Large Scale Topography of Io

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In order to investigate the large scale topography of Io we are using both limb observations and stereographic techniques applied to landmarks. The raw data for this study consists of Voyager 1 images of Io, 800 x 800 arrays of picture elements each of which can take on 256 possible brightness values. In analyzing this data we have had to identify and locate landmarks and limb points on the raw images, remove the image distortions caused by the camera electronics and translate the corrected locations into positions relative to a reference geoid. Minimizing the uncertainty in the corrected locations is crucial to the success of this project. In our highest resolution frames, an error of a tenth of a pixel in image space location can lead to a 300 meter error in true location. In our lowest resolution frames, the same error can lead to an uncertainty of several kilometers.

We have developed techniques to determine pixel-line positions of landmarks in Voyager images to sub-pixel accuracy. Instead of using the outline of a feature to define the landmark, we use the brightness data on the interior as well. Thus, for our purposes, a landmark is a circular patch of the surface whose variations in albedo or topography are sufficiently distinct to make identification possible in a variety of viewing situations. At the same time, the variations should be simple enough to allow for modeling with a relatively small number of parameters. This enables us to fit both the parameters in a brightness model and the offsets of the landmark positions from their nominal values simultaneously over a number of pictures.

For albedo variations, we model the brightness data as the sum of a few terms of the form

$$\Gamma^2 S/[(x-X)^2+(y-Y)^2+\Gamma^2].$$

Such a term produces a "bump" in the albedo of strength S at the point X,Y. Its half width at half maximum is Γ. Note that if S is negative,the "bump" becomes a "dip". For variations in topography, we use a few terms of the form

$$\Gamma^2 H[s_x(x-X)+s_y(y-Y)]/[(x-X)^2+(y-Y)^2+\Gamma^2]^2.$$

This form results from illumination of a topographic "bump" of the form $\Gamma^2 H/[(x-X)^2+(y-Y)^2+\Gamma^2]$ when the local sun vector has components s_x, s_y, s_z.

These parameterizations are useful for several reasons. First, in many cases they mimic the actual structure of the surface. This allows us to use a minimum number of terms. Second, if the "bumps" are sufficiently far apart, their parameters may be treated as if they were uncorrelated. Finally, this form of the model allows us to simplify the estimation process by doing some of the work analytically.

Image space locations of points lying on the limb are found by comparing the observed brightness dropoff in the neighborhood of the limb with that from an ideal surface having a possible (solved for) slow spatial variation in albedo. Before the comparison is made, the ideal brightness is convolved with a camera point spreading model.

The distortions of the image can be estimated from the distortion of the pattern of reseaus. It is difficult to locate reseaus precisely if the brightness is changing rapidly in their neighborhood.

But it is just such regions, limbs or areas of distinctive albedo fluctuations for example, which are of interest to us. We have developed a model for this distortion which can determine reseau locations to better than 0.1 pixels. It involves not only the effect of the brightness distribution within the picture but also the nonlinearity of the transfer function and the existence of charge outside of the region read by the vidicon scanning beam. In effect, it allows us to interpolate more reliably between reseaus.

The determination of the location of landmarks relative to the reference geoid has been speeded up considerably since our earlier studies. The key to this improvement is that the landmark locations relative to the body fixed frame are not directly correlated. They affect each other only through their mutual relationship to the camera pointing. Once the landmarks have been located in a reference frame which is rotating with Io, the center of that frame is determined relative to the geoid center by requiring that the mean square height of landmarks and limb points be a minimum.

Our latest results for landmark heights on Io show some softening from those of a year ago. This is primarily due to the elimination of errors which were not recognized then. The geoid, obtained from limb fitting and consistent with the landmark findings, has semi axes of 1832.6, 1821.9 and 1819.3 km with uncertainties of a few kilometers. The area of Pele is higher than the adjacent regions by about 4 km. Loki, Amaterasu, Manua and Fuchi Pateras are depressed as is Marduk. For the 120 landmarks which appear in three or more frames, the average height, relative to the geoid, is -1.4 km while the dispersion in heights is 2.8 km.

These results are preliminary. We have applied our landmark techniques to only twelve images and about one half of Io's surface. Since there are at least 50 more pictures available, we should be able to greatly improve both the extent and density of our coverage. By using pictures taken with different colors than the violet ones currently being used, we can check the consistency of our solutions and locate landmarks whose contrast is better at those frequencies. We are also studying the effect of satellite ephemeris and spacecraft trajectory errors on these results. Such errors will generally cause a bias in the height results which varies slowly with latitude and longitude. We suspect that the relative heights of neighboring landmarks will remain approximately the same. There is some evidence that such errors do exist and should therefore be solved out. For example, an apparent depression of the region near 180° (Colchis Regio) may be a symptom of this problem. However, most of the landmarks in this region are dark spots and these have been found to be low in other regions too.