THE MAPPING OF IRREGULARLY-SHAPED BODIES AT PLANETARY SCALE

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Abstract

Today the available materials on celestial bodies with irregular form permit the creation of maps on planetary and hemispheric scales. Up to now maps of celestial bodies on a planetary scale were created using traditional cartographic projections not taking into account the true shape of the physical surface. The problem of developing real surface projections displaying the irregular form of a celestial body on a planetary scale has been addressed.

Background

It is impossible to obtain a global view (without interruptions) of a celestial body in a single point perspective image. Therefore it is necessary to combine multiple images to show the whole surface of a body, and this requires the use of cartographic projections. The mapping of a body on planetary scale is very important in order to display significant knowledge about geology, geomorphology, albedo etc. (Fig. 1)

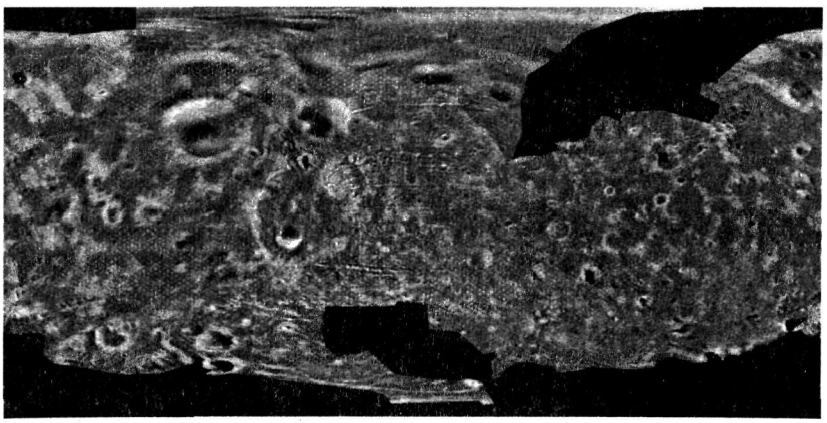

Figure 1. Map of Phobos albedo in a square cylindrical projection (P. J. Stooke). High albedo areas are shown in red.

Recent electronic or web atlases as well as traditional atlases have used for global mapping the equidistant along meridians square cylindrical projection and conformal triaxial ellipsoid projection. Before 1993 maps of celestial bodies on a planetary scale have been created using conventional cartographical projections without taking into account the irregular surface of a body:

- Phobos (Mars satellite) map in Mercator projection (Duxbury, 1974),
- Map of Deimos (Mars satellite) part in Mercator projection (Noland, Veverka, 1977),
- Phobos (Mars satellite) map in normal conformal projection of trixial ellipsoid (Bugaevsky, 1988)
- Map of Proteus (Neptune satellite) (Croft, 1992), the nucleus of comet Halley in square cylindrical projection

etc.

The problem of developing planetary scale map projections for celestial bodies taking into account the irregular surface was formed in MIIGAiK in 1993. Then the investigation in this direction was started.

The planetary mapping of irregularly shaped celestial bodies – miigaik method

It is known that cartographic projections are determined in different ways. The general method is that the plane coordinates and differential scales of projections are expressed as functions of the geographical coordinates. Therefore as the basis for development of projections of celestial bodies with irregular shapes the traditional cartographical projections have used in a modified way. As the reference surface the regular surface of a sphere (being most simple for calculation) is used, and the altitudes of points on the irregular surface are measured from the reference surface towards normal. In this case, the points will have the same latitudes and longitudes as on a regular surface (fig. 2).

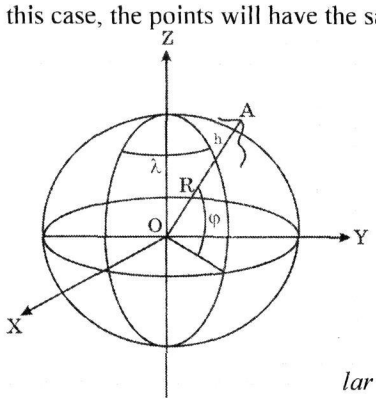

Figure 2. Coordinates of point A taking into account the irregular surface of a body in the planetocentric coordinate system of a sphere

The radii are calculated from the center of the sphere towards the normal.

For calculation of the data for projections it is necessary to know radius $R_i=R+h$ that is represented as matrix with a certain interval on latitude from -90° to +90° and longitude from 0° to 360°

In this case the common equations will be:

$$X = f_1(\varphi, \lambda, R_i);$$

$$Y = f_2(\varphi, \lambda, R_i).$$

Some American scientists have preferred to use maps of opposite hemispheres of a body to represent the whole surface. Three mutually orthogonal pairs of views (north and south polar regions, and hemispheres with axial meridians 0°, 90°, 180°, 270°), or four views from vertices of a tetrahedron illustrate the morphology of a body completely (e.g. Greeley and Batson 1997). For this reason the orthographic projection was recommended. But the orthographic view shows only one side of body at once and is insufficient to show the distribution of surface structures on planetary scale and determine their relationships. That proves the necessity for development of planetary projections.

Also, many planetary projections strongly distort Polar Regions or omit them from the map. Therefore it is often necessary to add special cartographic grids for mapping Polar Regions separately from the main map.

The MIIGAiK method offers mapping of the whole body including cartographic grids in a planetary scale and polar regions (north, south).

As an example of mapping we use Phobos, a satellite of Mars with mean radius $R=13,5$ *km*. For calculation of planetary Phobos projections the digital shape determined by Peter Thomas (USA) with interval 5° was used. Therefore only the large features of relief were mapped.

The choice of projections depends on the purpose of the map to be created - to represent a body in a planetary scale and at the same time to show its physical surface. The traditional projections used earlier for the small-scale maps of the Earth showing the whole surface, and also planetary projections used for the mapping of celestial bodies not taking in to account the irregular shape were taken into consideration. The main purpose is to visualize the irregular surface as clearly as possible to show distribution of major features.

The following projections are suggested to be the most useful: *The modified equidistant along meridians square cylindrical projection, The modified isocylindrical projection, The modified Sanson projection, The modified Kavraysky projection.* For calculation of distortion of these projections it is possible to use the known ways of approximation and polynomial equations. As an example we illustrate the planetary scale map of Phobos in the modified equidistant along meridians square cylindrical projection with addition north and south regions of the body in the modified orthographic projection for the whole representation of body (Fig. 3).

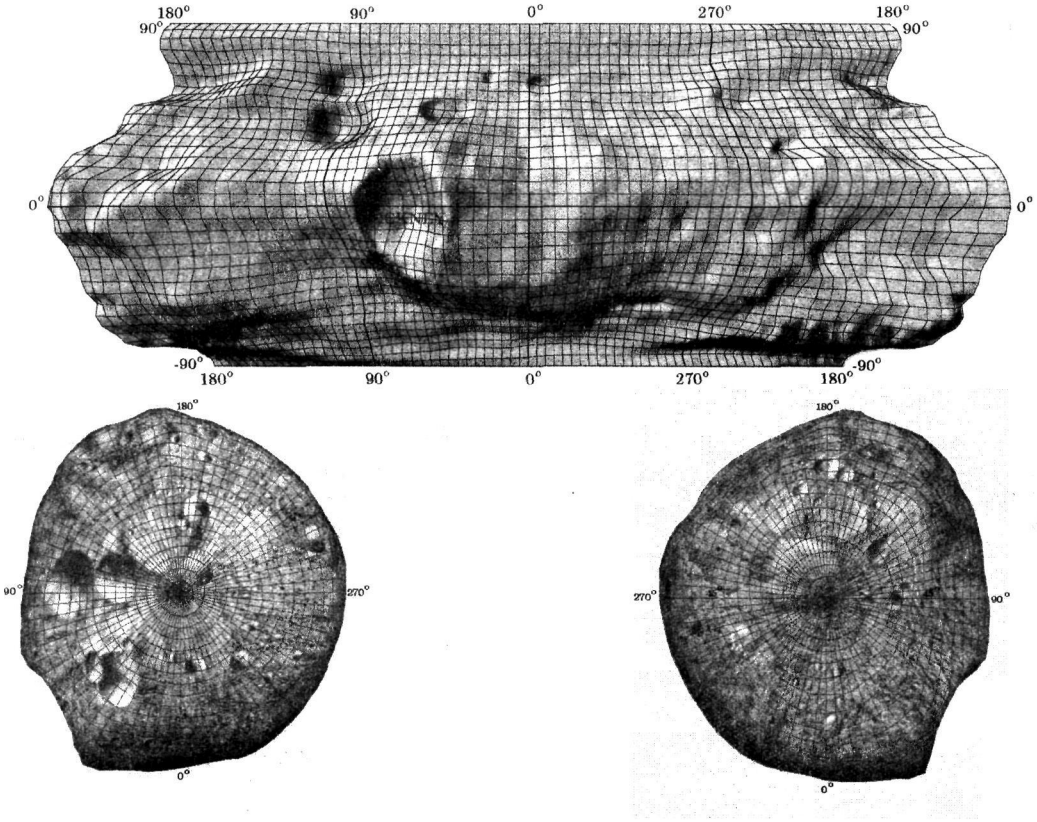

Figure 3. Cartographic grids of the irregular shape of Phobos in planetary projection (The modified equidistant along meridians square cylindrical projection) and polar regions of Phobos in polar projection (the modified orthographic projection). (M. V. Nyrtsov).

The planetary mapping of irregularly shaped celestial bodies – the Canadian method

A different approach has been followed in Canada. New map projections have been produced which are variations on conventional azimuthal projections. They differ from ordinary projections by using the local radius at every calculated point instead of a constant radius. The mathematical constant R in the equations presented previously is replaced by a variable number, which is calculated or taken from a shape model (Stooke and Keller 1990). The shape model may be a detailed topographic representation of the irregular shape, like those made by Peter Thomas of Cornell University for Phobos, or a triaxial ellipsoid, or other representations of shapes. These projections lose the characteristics of equal area or true shape, which they would have with a sphere, but they are useful for showing the cross-sectional shape of the mapped body. Because they illustrate shapes well they are called *Morphographic* (shape-drawing) *projections*. They are useful in regional or hemispheric scales, but not planetary scales, but unlike the American method of multiple orthographic views, they need only two views of opposite hemispheres for global mapping because the edges are represented better (Fig. 4).

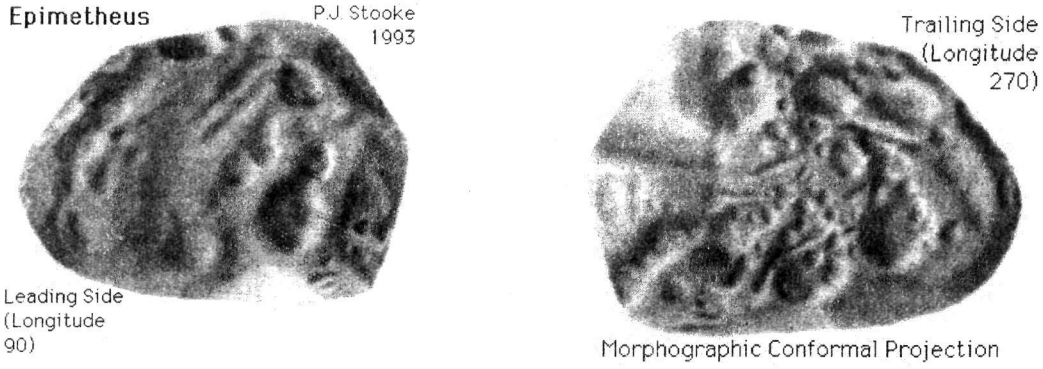

Figure 4. Satellites of Saturn - Epimetheus, morphographic projection. In this case the mapping shape model is the convex hull of the topographic shape model. (P. J. Stooke).

Another Canadian development was the reprojection of space images of a body into conventional or new map projections. The geometric correction part of a GIS program, normally used to remove relief distortions or earth curvature from satellite images, may be used to reproject a space image of an asteroid if a shape model grid can be added to the image. Grid intersections are used as control points to distort the image from a perspective projection to any other projection. The preferred approach is to reproject a set of images to one common projection such as equidistant along meridians square cylindrical projection (Fig. 5). Those images are combined to create a single global photomosaic. Then that mosaic can be reprojected to fit any of the new projections using the same control point method.

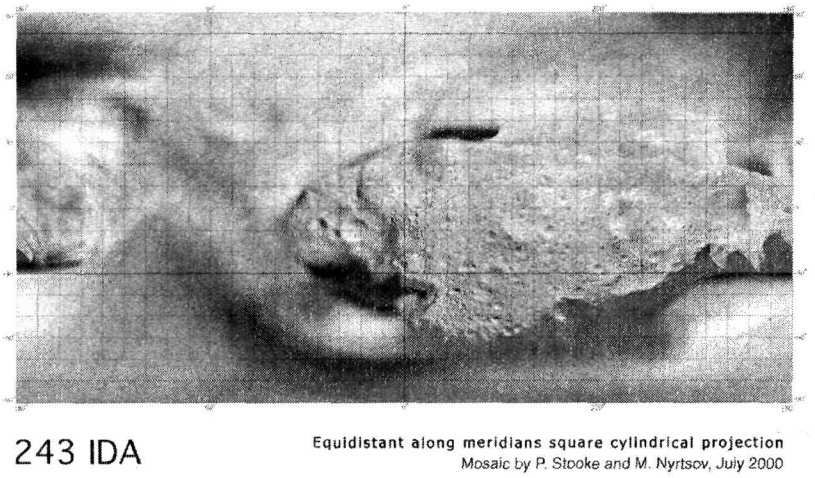

Figure 5. Asteroid Ida, planetary map using equidistant along meridians square cylindrical projection and Galileo spacecraft images. (P. J. Stooke and M. V. Nyrtsov).

Conclusion

Thus, there are three ways of global presentation of irregularly celestial body:

1. American method of multiple orthographic views (Three mutually orthogonal pairs of views (north and south polar regions, and hemispheres with axial meridians 0°, 90°, 180°, 270°)). The distortions are calculated with use of conventional equations.
2. Russian (The MIIGAiK) method that offers mapping of the whole body including cartographic grids in a planetary scale and polar regions (north, south). This method is use modified traditional planetary projections. For calculation of distortion of these projections it is possible to use the known ways of approximation and polynomial equations.
3. Canadian method using morphographic projections (modified conventional azimuthal projections) presented a body as two or three hemispheres). These projections lose the characteristics of equal area or true shape which they would have with a sphere, but they are useful for showing the cross-sectional shape of the mapped body
4. Another Canadian method connected to the reprojection of space images of a body into conventional or new map projections. The problem is, the known equations for distortion are not appropriate if the world itself is not a sphere. If we project the surface features of Eros along radii from the center onto a sphere, then project that sphere onto a conventional projection, the distortion at any point on the map will be a combination of the two procedures. If a conventional projection is used with a non-spherical body, the usual distortion equations must be modified to take into account the irregular shape of the body. The truth planetary mapping is to use planetary projections that present a body in planetary scale without break up.

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