MiARD

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Deliverable Report

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Table of Contents:

Summary

Given the high-resolution shape model of 67P/Churyumov-Gerasimenko (hereafter 67P) from deliverable D1.1 it is possible to generate a number of derived data products important for understanding the surface forming processes of the comet. D1.3 includes two distinct data sets:

1. maps of surface gravity properties (gravitational potential, surface g, local gravitational slope and dynamical height)
2. a partial map of albedo based of zero phase image data projected using the high-resolution shape (partial map because full coverage zero phase image data does not exist in the Rosetta image data base)

The gravity data has been calculated assuming a uniform density of cometary material and the numerical gravitational model of Werner and Scheeres.

Details (scientific and technological achievements)

1 Generation of the maps

Understanding gravity on a small irregular shaped body like 67P is a complicated and often unintuitive topic. But understanding gravity (basically understanding what is up and down at any point on the surface of the comet) is essential for understanding many of the processes that are active in forming the surface of the comet.

A gravity model for irregular shaped bodies has been implemented at DLR as a highly optimized multi-processor capable code. The model is based on an algorithm from Werner and Scheeres[1] . The software allows the calculation of the gravitational potential and force acting on a given point on the surface under the assumption that the internal density is constant. For highly irregular shaped bodies like 67P the gravitational field can be very complicated. The gravity model is combined with a fictive force model that describes the effects of the centrifugal force coming from the spin of the comet nucleus. The combined gravity plus centrifugal model describes the force material on the surface of the comet will experience at any point on the surface (ignoring the non-gravitational forces from the cometary activity).

Gravity model data has been calculated for each vertex point in the D1.1 global shape model. The 20M (20 million) facet model has been processed using a 125K facet decimated shape model and the 44M facet model has been processed using a 25K facet decimated model. The gravity model uses a reduced resolution shape as input for the calculations in order to keep the computational time under control. Even so, calculating gravity data for the 20M facet D1.1 model using a 125K facet model for the gravity calculations takes about 48 hours using an 88-core computer. Experience with the gravity model indicates that the error introduced by doing the gravity calculation with the full resolution shape as compared to doing the calculations with a 20K facet decimated model is less than 0.1%. The raw numerical data per vertex is included in the D1.3 delivery.

The gravitational model data has been visualized using DLR data projection software which takes spacecraft position/attitude data, spacecraft image data and vectorised data (gravity data for example) as input for producing 2D map products and 3D projected models as output.

The following figures show examples of the visualized data products. Figure 1 to Figure 5 show examples of the different data parameters available in the D1.3 delivery. Each figure illustrates a different map/3D projection type and a different data parameter included in the delivery. However, all projections are available for all the data parameters.

The following projections are available:

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[1] R A Werner and D J Scheeres (1997), Celestial Mechanics and Dynamical Astronomy **65**(3) pp313-344

1. Global maps using the equidistant cylindrical map projection
2. SL, BL and NR frame global maps using equidistant cylindrical (limited to frame specific data)
3. Hemispherical (North and South) regional maps using the Lambert azimuthal equal area map projection
4. 3D colorized models in PLY shape format

The following data parameters are available:

1. Surface gravitational potential
2. Surface g
3. Surface local gravitational slope
4. Surface dynamical height.
5. Surface 610nm zero phase albedo

Figure 1 shows an example of an equidistant cylindrical map projection of the gravitational potential. The top of the figure shows the global map as represented by the Cheops body fixed coordinate system with the zero longitude in the centre of the map.
Because of the irregular shape of the comet nucleus it is not possible to project all points on the surface (in 3D space) onto a unique 2D map. To work around this problem three lobe specific coordinate systems have been defined (the SL, BL and NR frames, see Preusker et al. 2015). The SL frame is optimised for mapping the small lobe, the BL frame is optimized for mapping the big lobe and the NR frame is optimized for mapping the neck region of the comet. The bottom of Figure 1 shows an example of three lobe specific maps with the white background color making areas excluded from the map. For example, the SL map excludes the regions on the comet covered by the NR and BL frames and so forth.

Figure 2 shows Lambert azimuthal equal area regional maps of the northern and southern hemispheres with the dynamical height as data parameter. The dynamical height is the equivalent distance from the center of a point mass with the same mass as the comet nucleus that would give the same gravitational potential as calculated from the irregular shape model:

$$H_{dyn} = -\frac{GM}{P_{ws}}$$

H_{dyn} is the dynamical height, G is the gravitational constant, M is the total mass of the comet nucleus and P_{ws} is the gravitational potential calculated using the Werner and Scheeres model. Dynamical height is a convenient way to illustrate which areas are highlands and which areas are lowlands. On the comet the Hapi region stands out as the lowest point on the surface (The region that includes the north pole in the northern hemisphere map). But in addition it can be seen that the Imhotep region (~300° longitude, ~-60° latitude in the southern hemisphere map) is almost as deep as the Hapi region. In the images Imhotep seems to be a medium to high point on the comet surface which illustrates the importance of understading the gravity field.

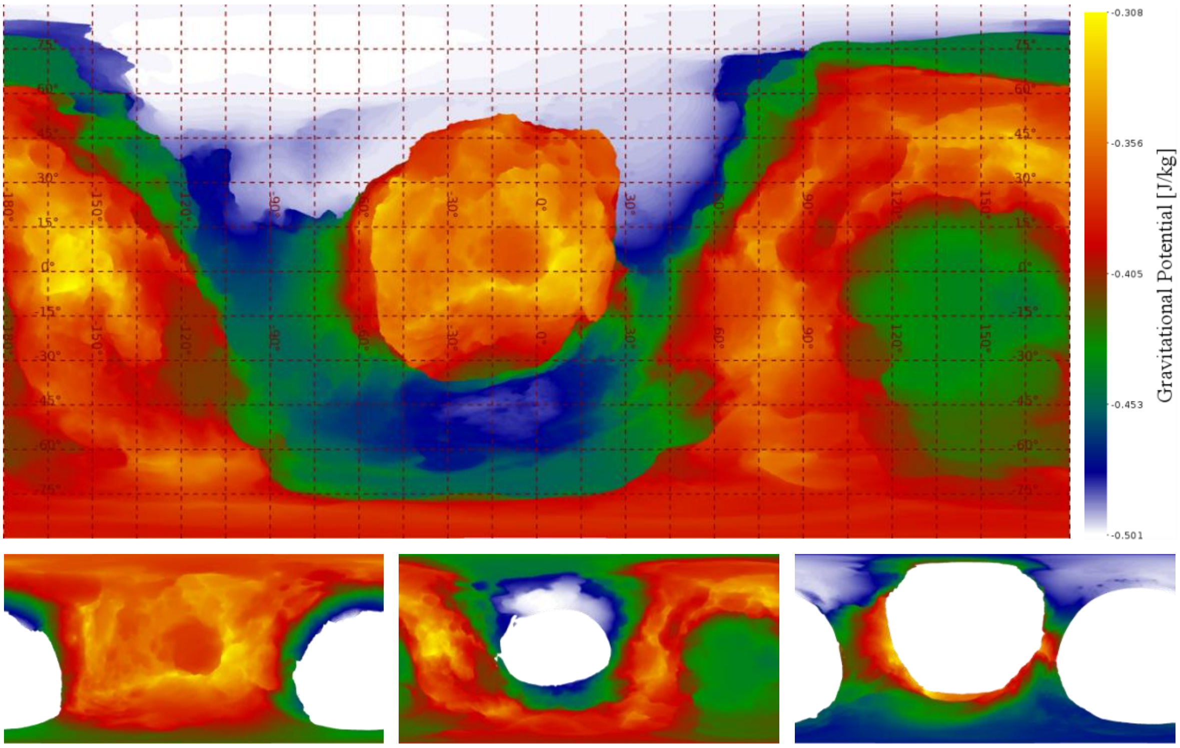

Figure 1. **Equidistant Cylindrical projected 2D maps showing the gravitational potential [Jkg^{-1}] over the surface of 67P. (top) the global map in the Cheops coordinate frame (bottom) three maps with the data projected on the lobe specific coordinate frames (SL, BL, NR)**

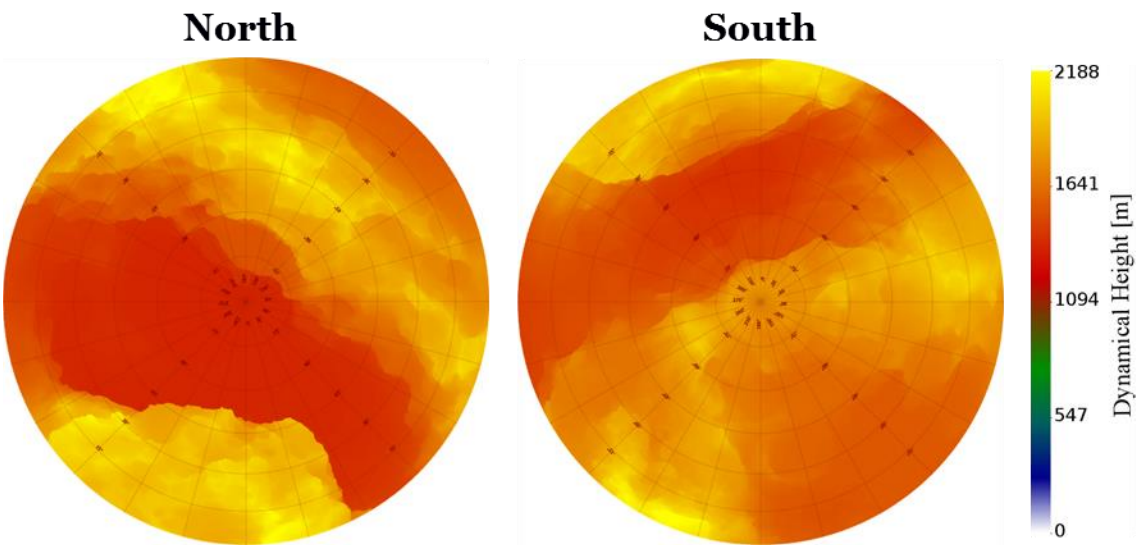

Figure 2. **Lambert azimuthal equal area maps of the northern and southern hemisphere of 67P showing the dynamical height of the surface.**

Figure 3 shows Lambert azimuthal equal area regional maps of the northern and southern hemispheres with the effective surface g as data parameter. The g value includes the centrifugal term thus taking the spin into account. Note that the g values in the delivery are given in units of mm.s^{-2} instead of the SI unit m.s^{-2} for project historical reasons.

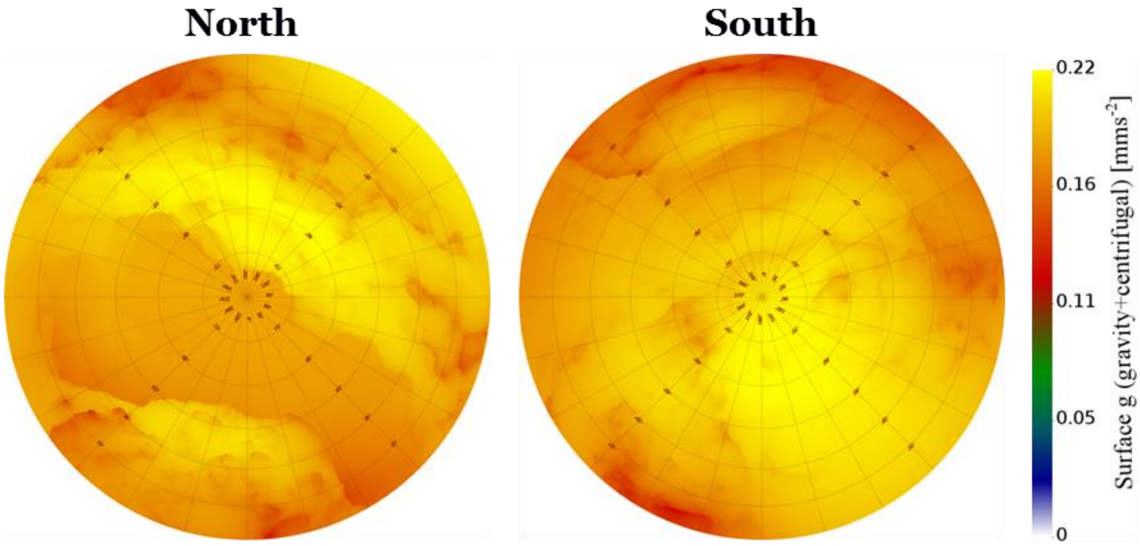

Figure 3. Lambert azimuthal equal area maps of the northern and southern hemisphere of 67P showing the magnitude of the surface gravitational + centrifugal force per mass unit on the surface (g). Note the non SI unit mm.s^{-2}.

Figure 4 illustrates a 3D projected view of the local gravitational slope. These 3D views are included in the delivery in the form of colorized PLY-formatted 3D shape models which can be displayed in a PLY capable 3D viewer like Meshlab (http://www.meshlab.net/). The views are limited to the range from 0° to 90° clipping slopes higher than 90°. Slopes higher than 90° exists at a number of places (overhangs) but only represent a very small fraction of the surface area.

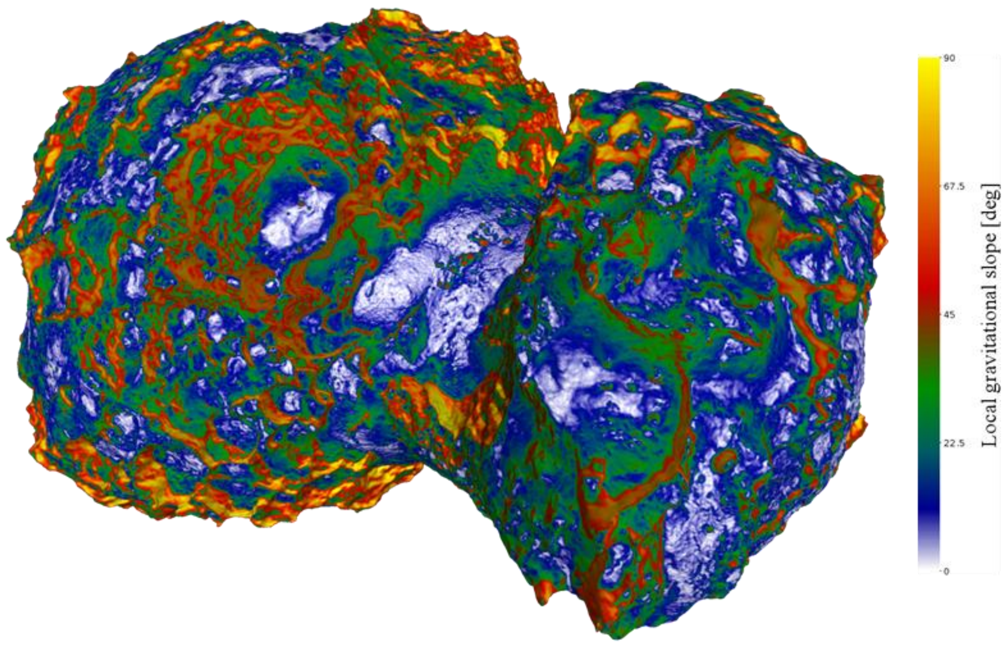

Figure 4. 3D view of 67P with the local gravitational slope projected on the surface with a color scale. White and blue colors represent low slopes and red/yellow colors represent high slopes. The illustrated view shows the small lobe of the comet and the Seth and Hapi regions.

Figure 5 shows a 3D view with VIS610 OSIRIS-WAC images data from the Rosetta zero phase fly-by on April 9 2016 23:29 to April 10 2016 00:32. The albedo maps included in the D1.3 delivery are the zero phase albedo for 610 nm wavelength based on image data with phase angle less than 5°.

The albedo maps included in the delivery do not have global coverage. The coverage is limited by the availability of zero phase angle image data as acquired by the Rosetta mission. Rosetta, because of operational constraints, did not allow much observational time with the spacecraft located over the sub solar point.

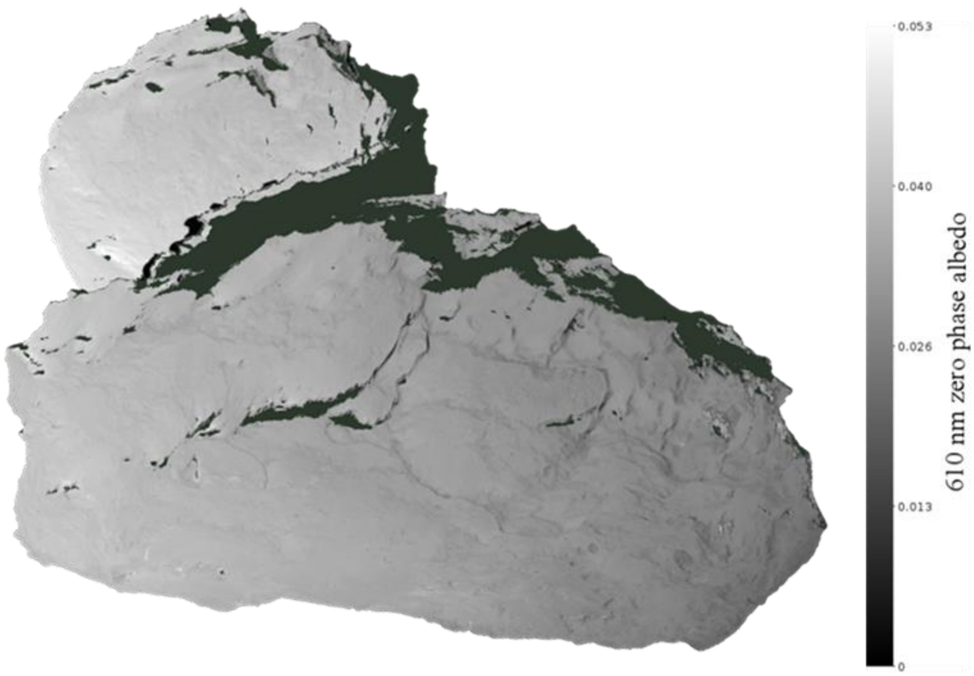

Figure 5. 3D view of 67P with an albedo map projected onto the surface. The view shows the Imhotep and Hathor regions on the comet which are well covered by the available image data. Dark areas represent no data.

2 Description of the D1.3 products

The D1.3 data products archive is separated into the top level sections “gravity” and “albedo”. The “gravity” node (or directory) contains the gravity maps and the “albedo” node contains the albedo maps. These datasets are too large for the EC’s deliverable submission system, so will be made available through the project’s website at www.miard.eu as well as other channels.

2.1 Description of the D1.3 gravity data products

The gravity node contains data and maps related to the gravity parameters calculated using the D1.1 global shape model and the Werner and Scheeres 1997 irregular shape gravity model. The model assumes a constant density derived from the measured mass of the comet nucleus of $9.982\ 10^{12}$ kg[2] and the volume of the D1.1 global shape model. The gravity calculations have been made using the 125K facet decimated reference shape selected by the MiARD project (25K for the 44M facet version of the D1.1 shape). The gravity model has been calculated using the pre-perihelion nucleus spin period of 12.403 hours.

The following gravitational parameters are included:

Name	Description
potential	The gravitation potential [Jkg^{-1}]
dynamical_height	The dynamical height is the distance from the center of the body which would produce the gravitational potential as a given vertex point in the shape model assuming that all the mass of the comet is found as a point mass at the the center of the shape [km]
gc	The surface acceleration including both the gravitational g and the centrifugal force [mms^{-2}] (Note the non SI unit)
slope_gc	The local terrain slope relative to the local gravitational field (including centrifugal force)

The gravity node contains the following sub sections:

1. 3D
2. maps
3. data

(3D) The 3D folder contains 3D models in PLY format with physical parameters overlaid onto the 3D shape using a color palette.

The files follow the naming convention:

shape_<parameter>.ply - the 3D model of <parameter>

shape_<parameter>_colorbar.svg - The colour bar defining the colour scale

(maps) The maps node contains map projected data using the following naming convention

<map projection>/<parameter>_<projection info>_ms<height><fr>.<ext>

[2] Pätzold et al. 2016

Name	Description
map projection	The map projection used to produce the maps the dataset includes two map projections: a) Equidistant cylindrical global maps using the Cheops, SL, BL and NR coordinate frames b) North/South polar view Lambert azimuthal equal area regional maps using the Cheops coordinate frame
parameter	The gravitational parameter being projected (see above)
projection info	Information about the map projection being used (zero longitude, zero latitude)
height	The height in pixels of the map The D1.3 maps have been generated with a 0.05° angular resolution.
fr	The coordinate frame used for the projection Cheops: The global body fixed frame used for 67P SL: The Small lobe specific coordinate frame BL: The Big lobe specific coordinate frame NR: The neck region specific coordinate frame see Preusker et al. (2015)[3] for definition of the coordinate frames SL = 67P/C-G_SL_FIXED BL = 67P/C-G_BL_FIXED NR = 67P/C-G_NR_FIXED
ext	The file type .img - PDS v3 formatted image files .png - Quick look image files in PNG format .svg - Annotated image in SVG format

[3] Preusker et al. "Shape model, reference system definition, and cartographic mapping standards for comet 67P/Churyumov-Gerasimenko – Stereo-photogrammetric analysis of Rosetta/OSIRIS image data" (2015) Astronomy & Astrophysics vol 583

	_colorbar.svg - The color bar used in the PNG and SVG image files

(data) The data node contains the actual numerical gravity data used for the map products. The data is stored in PDS v3 image files with the filenaming convention:

<original shape>_<density>-<period>-<model resolution>_ws.grav.vertex.img

<original shape> is the filename of the original shape model (the D1.1 shape) for which the gravity calculations have been performed

<density> is the constant density assumed for the gravity calculations

<period> is the assumed spin period of the comet nucleus

<model resolution> is the number of facets in the shape model used for the gravity model calculations.

The gravity data is stored with each gravitational parameter as a separate column with a row for each vertex in the source shape model. The data files contain column data for the following parameters:

Name	Description
Potential	The gravitational potential
Fg_x **Fg_y** **Fg_z**	The surface gravitational force vector (just gravity)
Fc_x **Fc_y** **Fc_z**	The surface centrifugal force vector
Fgc_x **Fgc_y** **Fgc_z**	The combined gravitational and centrifugal force vector
fc/fg	The ratio between the magnitude of the centrifugal and gravitational force
g	Surface acceleration (just gravity)
gc	Surface acceleration (centrifugal + gravity)
slope_g	Local gravitational slope (just gravity)

slope_gc	Local gravitational slope (centrifugal + gravity)
dynamic_height	The dynamical height of each vertex point

2.2 Description of the D1.3 albedo data products

The albedo maps have been generated using 610 nm OSIRIS-WAC filter images from the zero phase flyby phase acquired April 9 2016 23:29 to April 10 2016 00:32. The mapped data is πI/F of images acquired for phase angles 0° to 5°. The mapped data is thus close to, but not exactly equal to, the zero phase albedo. The map coverage is not global because the input data set does not have global coverage.

The albedo node contains two sub nodes “3d” and “maps” with content following the same scheme as the gravity data node. However, coordinate frame maps exist only for the combination with valid data.

Deviations from the DoA

None

Conclusions, expected impact and use of deliverable, outlook

Understanding the surface gravity of 67P is essential for interpreting the landforms there, and so for understanding the surface forming processes active on cometary nuclei in general. The maps and data generated for this deliverable are therefore expected to be of general interest for the scientific community engaged in the study of comets and other small airless bodies. In addition, the gravity data is required within the MiARD project, in particular for deliverable D1.5 " Manuscript on the final shape of the nucleus, with surface slope and surface gravitation".

GLOSSARY

OSIRIS-WAC	Wide angle camera on the OSIRIS instrument
PDS	Planetary Data System. Refers to a data and metadata standard
PLY	Polygonal file format for 3D models
PNG	Portable Network Graphics. an image format
SVG	Scalable Vector Graphics. An image format