esac

European Space Astronomy Centre
(ESAC) European Space
Agency (ESA) Camino Bajo del
Castillo s/n Urb. Villafranca
del Castillo
28692 Villanueva de la Canada - Madrid
SPAIN

NEW DIGITAL TERRAIN MODEL OF THE HUYGENS LANDING SITE

Prepared by **Chloe Daudon**
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1. Introduction

Landscapes of Titan, the largest moon of Saturn, have been observed during nearly 13 years in the frame of the Cassini-Huygens mission. The wide range of observed morphologies (dunes, mountains, seas, lakes, rivers, etc.) testifies to the singular geological richness that Titan shares with the Earth. To better understand the processes at work that sculpt these formations, one needs accurate digital terrain models (DTM). This study is focused on the Huygens landing site, a flat landscape surrounded by hills supposedly incised by river valleys. Two DTM of this site have been produced by USGS from images acquired by the DISR (Descent Imager/Spectral Radiometer) cameras and using the SOCET SET photogrammetry software: they focused on the river network and on the plain (Tomasko et al., 2005; Soderblom et al., 2007). Automated matching was unsuccessful due to poor image quality, so these DTM were generated manually and then interpolated onto a regular grid. However, this approach is non-reproducible and the DTM (hereafter called USGS-DTM) displays inconsistencies in reconstructed topographic features. We investigated a new approach, benefiting from a recent re-processing of the DISR images correcting both the radiometric and geometric distortions (Karkoschka et al., 2007; Karkoschka & Schröder, 2016; Karkoschka et al., 2016), and from a photogrammetry package based on an automatic open-source shape-from-motion algorithm. The method used to overcome the data limitations is fully explained and documented in Daudon et al., 2020. The resulting DTM (hereafter called IPGP-DTM) provides the best available spatial sampling of Titan's landscape (18 m) and increases the size of the reconstructed region up to 10.3 km^2 (against 7.5 km^2 before).

1.1 Instrument and dataset

The DISR (Descent Imager/Spectral Radiometer) downward looking instruments onboard the Huygens probe includes three panchromatic cameras: the Side Looking Imager (SLI), the Medium Resolution Imager (MRI), and the High Resolution Imager (HRI). The light is transmitted from the lens system of each camera to a shared CCD device through optical fiber bundles.

Camera	Focal length (mm)	Sensor size (mm)	Zenith range (°)	Size (pixel)
SRI	6.262	2.94 × 5.88	45.2-96	128 × 256
MRI	10.841	4.05 × 5.88	15.8-46.3	176 × 256
HRI	21.463	3.68 × 5.88	6.5-21.5	160 × 256

Eight stereoscopic images (#414, #420, #450, #462, #471, #541, #553, and #601) were selected for the photogrammetric reconstruction of the IPGP-DTM owing to their optimal areas of overlap and resolutions.

We also used new navigation data (SPICE kernels) giving the position and orientation of the Huygens probe during the descent. They were first computed by the Huygens Descent Trajectory Working Group (DTWG) and they have recently been recalculated by the ESA SPICE Service (https://doi.org/10.5270/esa-ssem3np).

The processing of the images and the navigation data are detailed in Daudon et al. (2020), section 2.

1.2 Abbreviations and Acronyms

CCD Charge-Coupled Device

DISR Descent Imager/Spectral Radiometer

DTM Digital Terrain Model

DTWG Descent Trajectory Working Group

DUG Data User Guide

ENSG Ecole nationale des sciences géographiques

EP Expected vertical precision

ESA European Space Agency

HRI High Looking Imager

IGN Institut national de l'information géographique et forestière

IPGP Institut de physique du globe de Paris

MRI Medium Looking Imager

PSA Planetary Science Archive

SLI Side Looking Imager

USGS United States Geological Survey

1.3 Reference and Applicable Documents

Daudon, C., Lucas, A., Rodriguez, S., Jacquemoud, S., Escalante López, A., Grieger, B., Howington-Kraus, E., Karkoschka, E., Kirk, R., Perron, T., Soderblom, J., & Costa, M. (2020). A new Digital Terrain Model of the Huygens landing site on Saturn's largest moon, Titan. *Earth and Space Science,* https://doi.org/10.1029/2020EA001127.

Karkoschka, E. (2016). Titan's meridional wind profile and Huygens orientation and swing inferred from the geometry of DISR imaging. *Icarus*, 270, 326-338 (surface and atmosphere of Titan).

Karkoschka, E., & Schröder, S.E. (2016). The DISR imaging mosaic of Titan's surface and it's dependence on emission angle. *Icarus*, 270, 307-325 (surface and atmosphere of Titan).

Karkoschka, E., Tomasko, M.G., Doose, L.R., See, C., McFarlane, E.A., Schroder, S.E., & Rizk, B. (2007). DISR imaging and the geometry of the descent of the Huygens probe within Titan's atmosphere. *Planetary and Space Science*, 555(13), 1896-1935. (Titan as seen from Huygens)

Pierrot-Deseilligny, M., & Clery, I. (2011). Apero, an open source bundle adjustment software for automatic calibration and orientation of set of images. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XXXVIII-5, 269-276.

Pierrot-Deseilligny, M., & Paparoditis, N. (2006). A multiresolution and optimization-based image matching approach: An application to surface reconstruction from SPOT5-HRS stereo imagery. *ISPRS Workshop on Topographic Mapping from Space (With Special Emphasis on Small Satellites)*, 5 pp.

Tomasko, M.G., Archinal, B., Becker, T., Bézard, B., Bushroe, M., Combes, M., et al. (2005). Rain, winds and haze during the Huygens probe's descent to Titan's surface. Nature, 438(7069), 765-778.

Soderblom, L.A., Tomasko, M.G., Archinal, B.A., Becker, T.L., Bushroe, M.W., Cook, D.A., et al. (2007). Topography and geomorphology of the Huygens landing site on Titan. *Planetary and Space Science*, 55(13), 2015-2024.

2. Scientific objectives

River valleys on Titan have been observed at all latitudes by the Cassini-Huygens mission. Similar to erosion by water on Earth, liquid methane carves into the substrate to form these rivers, particularly stunning in the images acquired near the equator by the Huygens probe. To better understand the processes at work that sculpt these formations, one needs accurate digital terrain models (DTM) of this region where the highest resolution images are available. A DTM of the Huygens landing site has been produced by USGS from images acquired by the DISR (Descent Imager/Spectral Radiometer) cameras and using the SOCET SET photogrammetry software (Soderblom et al., 2007). However, this DTM displays some inconsistencies in the topographic features observed, partly due to the non-optimal configuration of the data available at that time (geometry of acquisition, but also poor compression quality, geometric distortion and poor navigation). Recent re-processing of the images and Huygens navigation allow for the computation of a new DTM (IPGP-DTM) with higher spatial resolution and coverage, and more consistent geological settings (Daudon et al., 2020).

2.1 Acknowledgements

The authors want to thank Chuck See for providing the re-processed DISR images.

Users are requested to acknowledge the dataset by citing both the DOI of the dataset and the paper:

Daudon, C., Lucas, A., Rodriguez, S., Jacquemoud, S., Escalante López, A., Grieger, B., Howington-Kraus, E., Karkoschka, E., Kirk, R., Perron, T., Soderblom, J., & Costa, M. (2020). A new Digital Terrain Model of the Huygens landing site on Saturn's largest moon, Titan. *Earth and Space Science, accepted.*

3. Data product generation

The construction of the IPGP-DTM was performed using MicMac, a free and open-source photogrammetric suite developed by IGN (Institut national de l'information géographique et forestière) and ENSG (Ecole nationale des sciences géographiques), cf. Pierrot-Deseilligny & Paparoditis (2006), Pierrot-Deseilligny & Clery (2011), Bretar et al., (2013).
Batch commands can be run from a command line and the three main steps of the photogrammetric reconstruction (homologous points search, absolute orientation, and depth map construction) are divided into 5 sub-steps corresponding to different commands (see Figure 1). The entire reconstruction process is fast (i.e., about 5 minutes on a dual socket Xeon workstation) when working on small images (5 images 256 x 160 pixels and 3 images 256 x 176 pixels). The workflow is illustrated in Figure 1. The entire procedure leading to the new DTM, the comparison with the previous one (USGS-DTM), and its validation are described in details in Daudon et al. (2020).

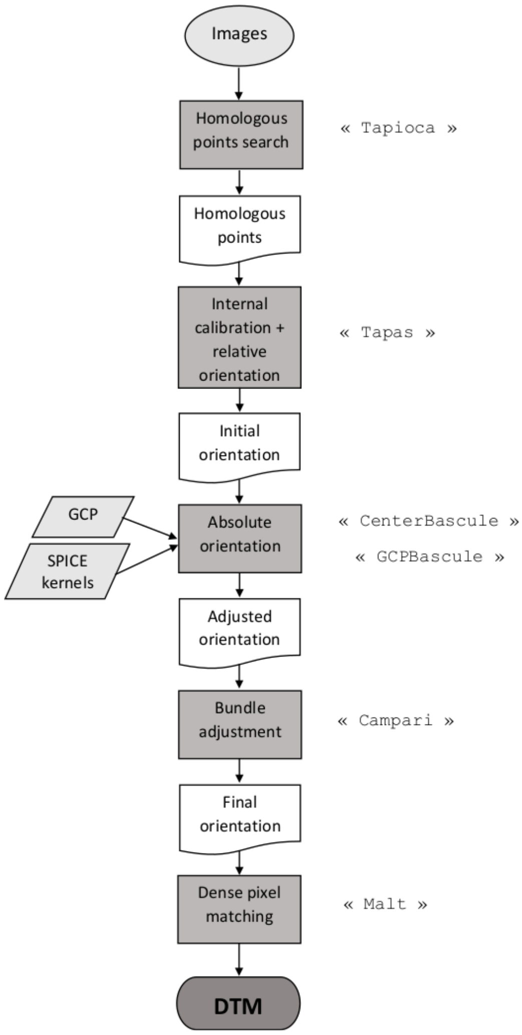

Figure 1: Summary diagram of the IPGP-DTM extraction workflow. GCP refers to ground control points. The MicMac commands are mentioned in quotation marks along with the corresponding steps in the workflow (Daudon et al., 2020)

4. Archive format and content

4.1 Product and format type

- DTM (named “IPGP_DTM”): int16; 1 channel; tiff image
- DTM metadata (named “IPGP_DTM.tfw”): tfw file
- Orthorectified mosaic (named “IPGP_Ortho”): int16; 1 channel; tiff image
- Mosaic metadata (named “IPGP_Ortho.tfw”): tfw file
- 8 images: int16; 1 channel; tiff image

4.2 DTM and mosaic specifications

- Tangent frame: Local (see Appendix)
- DTM resolution: 18 m/ pixel
- Mosaic resolution: 18 m/pixel
- Metadata files:
  - line 1: x-component of the pixel width (x-scale)
  - line 2: x-axis rotation
  - line 3: y-axis rotation
  - line 4: y-component of the pixel height (y-scale), typically negative
  - line 5: x-coordinate of the origin point (upper left pixel)
  - line 6: y-coordinate of the origin point (upper left pixel)

5. Known issues

The reconstructed area of the IPGP-DTM is limited to regions that satisfy a quantitative criterion of quality based on the value of both the correlation score (here > 0.5) and the theoretical expected vertical precision (< 450m), also called EP. The expected precision is based on the geometry of acquisition and the image resolution and gives an estimation of the best achievable accuracy (see Daudon et al., 2020).
However, the edges and the bottom of the IPGP-DTM are unusually steep (see Figure 2). We didn't mask them because of high correlation scores but they display the highest EP values (two to three time higher than in the center of the DTM).

As a consequence, we advise users to treat these areas carefully and to prioritize the central area of the IPGP-DTM that is more accurate. Further explanations are available in Daudon et al. (2020).

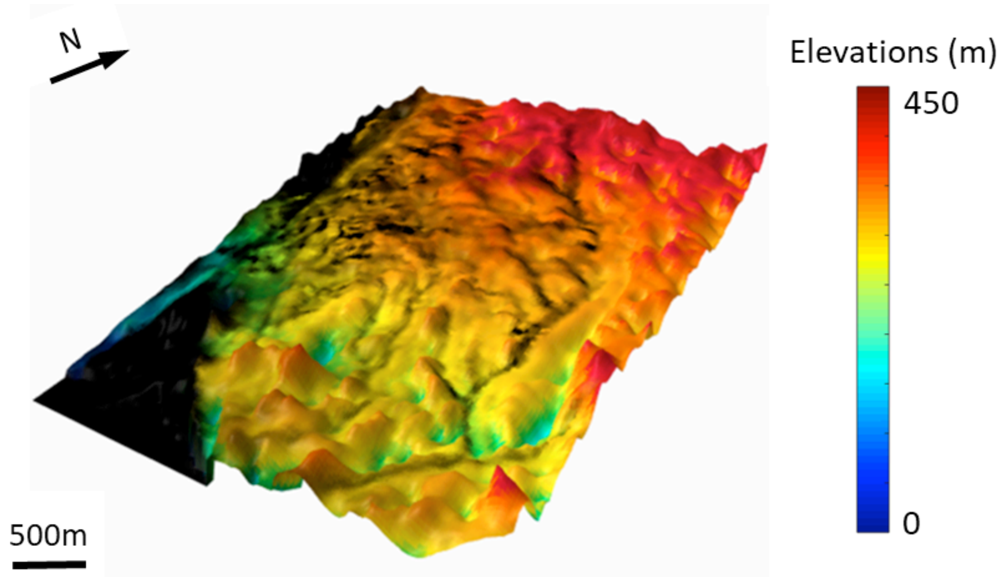

Figure 2: 3D view of the IPGP-DTM with its corresponding orthorectified mosaic superimposed on it.

6. Software

MicMac is free and open source. Indications to install it are explained here:
https://micmac.ensg.eu/index.php/Install

For more details concerning the parameters used for the IPGP-DTM reconstruction, see the Supplementary Information of Daudon et al. (2020).

7. Appendix: Local tangent frame

The Local Tangent Plane (LTP) is an orthogonal, rectangular, reference system the origin of which is defined at an arbitrary point on the planet surface (here we took the nadir of the image #450 located at (167.64370°E, -10.577749°N)). Among the three coordinates one represents the position along the northern axis, one along the local eastern axis, and the last one is the vertical position. If (λ,φ,h) are the coordinates of a given point in the geographical frame, the coordinates (xt,yt,zt) of the LTP are defined as:

$$\begin{pmatrix} xt \\ yt \\ zt \end{pmatrix} = \begin{pmatrix} -sin\varphi & cos\varphi & 0 \\ -\cos\varphi\sin\lambda & -sin\lambda sin\varphi & cos\lambda \\ cos\lambda\cos\varphi & cos\lambda\sin\varphi & sin\lambda \end{pmatrix} \begin{pmatrix} x - x_0 \\ y - y_0 \\ z - z_0 \end{pmatrix}$$

With:

- (x; y; z) the Cartesian coordinates of the given point
- (x_0; y_0; z_0) the Cartesian coordinates of our reference point