HRSC DIGITAL TERRAIN MODEL AND TERRAIN-Corrected IMAGES OF THE SOUTH POLE OF MARS

Prepared by UCL Team
Date of Issue 17/05/2019
## APPROVAL

## CHANGE LOG

<table>
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<tr>
<th>Reason for change</th>
<th>Issue</th>
<th>Revision</th>
<th>Date</th>
</tr>
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<tr>
<td>Initial version</td>
<td>1</td>
<td>0</td>
<td>25/03/2019</td>
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## CHANGE RECORD

<table>
<thead>
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<th>Issue 1</th>
<th>Revision 0</th>
<th>Reason for change</th>
<th>Date</th>
<th>Pages</th>
<th>Paragraph(s)</th>
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<td>Updated version</td>
<td>17/05/2019</td>
<td>All</td>
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Table of contents:
1. Introduction .......................................................................................................................... 4
1.1 Instrument and Datasets ..................................................................................................... 4
1.2 Abbreviations and Acronyms ............................................................................................ 4
1.3 Reference and Applicable Documents ............................................................................... 5
2. Scientific Objectives ............................................................................................................ 6
2.1 Acknowledgements ........................................................................................................... 6
3. Data Product Generation ..................................................................................................... 7
4. Archive Format and Content ............................................................................................... 8
4.1 Product Type ....................................................................................................................... 8
4.2 Naming Convention ........................................................................................................... 8
4.3 Format Type ....................................................................................................................... 8
4.4 DTM/ORI Specification .................................................................................................... 8
4.5 Product Example and Usage ............................................................................................ 9
5. Known Issues ...................................................................................................................... 14
6. Software ................................................................................................................................ 15
1. INTRODUCTION

Within the EU FP-7 iMars project (http://www.i-mars.eu), it was realised that a complete Martian South-Polar Digital Terrain Model would be helpful for Martian polar research. An enhanced processing system (Kim and Muller, 2009) based on the NASA-VICAR-based pipeline developed by JPL (Jet Propulsion Laboratory) with modifications from DLR (German Aerospace Centre) was employed for this purpose. The main modification from UCL was replacing the imagematcher with the Gotcha (Gruen-Otto-Chau) algorithm (Shin and Muller, 2012) and applying this to a specialised setup for the polar region using 64-bit processing.

HRSC orbital strip DTM products were produced on an areoid (gravity) reference surface with a resolution of 50 m/pixel in the same co-ordinate system as the gridded Mars Orbiter Laser Altimeter (MOLA) of 512 pixels/degree (112 m/pixel) over the South Polar Residual ice Cap (SPRC). MOLA includes a gap over the Mars South Polar region (82° - 90° S) whereas the HRSC products cover this gap. These orbital strip-based products were then mosaiced into a 50m/pixel DTM and a 12.5m/pixel OrthoRectified Image (ORI) of the panchromatic channel. See (Putri et al., 2019) for further details.

The accuracy of the HRSC orbital 50m DTMs were assessed against the MOLA reference with good results (loc.cit.). These validated products are being made open-source to the planetary science community through a collaboration with ESA PSA. In addition, browse products have been produced using colour-height hill-shading and these browse products are visualisable through the iMars WebGIS system (http://www.i-mars.eu/webgis). The individual orbital HRSC DTM & ORI products as well as the mosaiced 50m DTM and 12.5m panchromatic ORI image mosaics are downloadable from the aforementioned link.

1.1 Instrument and Datasets

The High Resolution Stereo Camera (HRSC) onboard of the European Space Agency (ESA) Mars Express is a pushbroom camera with 9 different characteristics at 9 different angles: one nadir panchromatic channel (0°), two stereo channels (±18.9°), four-band colour channels (Red (15°), Green (2.4°), Blue (- 2.4°), and Near Infra-Red(-15°)) and two photometry channels (±12.8°). HRSC started its operation in 2003 (MY26), HRSC is still working until the present-day (2019) (MY35).

Overlapping HRSC strips over the Martian South Pole were selected based on spatial and temporal coverage to produce single DTM strips and the corresponding ORIs. The DTM strips and ORIs were then merged into separate mosaiced product.

1.2 Abbreviations and Acronyms

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>DLR</td>
<td>German Aerospace Centre</td>
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<tr>
<td>DTM</td>
<td>Digital Terrain Model</td>
</tr>
<tr>
<td>DUG</td>
<td>Data User Guide</td>
</tr>
<tr>
<td>ESA</td>
<td>European Space Agency</td>
</tr>
<tr>
<td>EU FP-7</td>
<td>European Union’s Seventh Framework Programme</td>
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<tr>
<td>GIS</td>
<td>Geographic Information System</td>
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<tr>
<td>HRSC</td>
<td>High-Resolution Stereo Camera</td>
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<tr>
<td>JPL</td>
<td>Jet Propulsion Laboratory</td>
</tr>
<tr>
<td>MOLA</td>
<td>Mars Orbiter Laser Altimeter</td>
</tr>
<tr>
<td>MY</td>
<td>Martian Year</td>
</tr>
</tbody>
</table>
1.3 Reference and Applicable Documents


2. SCIENTIFIC OBJECTIVES

Over the past 5 decades, many areas on Mars have been imaged with serendipitous stereo, mainly to improve the potential for scientific studies. The rapid progress in planetary surface reconnaissance instrumentation, especially in relation to 3D imaging of the surface, has allowed change detection analysis. For example, by overlaying different high-resolution imagery from distinct time epochs (starting back in the mid 1970’s) one can examine dynamic features, such as the recent discovery on Mars of mass (e.g. boulder) movement, tracking inter-year changes of seasonal phenomena (e.g. Swiss Cheese Terrain) and looking for fresh craters from meteoritic impacts.

The south pole of Mars is an area where a lot of these changes occur. It is commonly accepted in the planetary science community that research greatly benefits from the availability of high-resolution 3D models of Mars in general and the south pole of Mars, in particular. Within the EU FP-7 iMars (http://www.imars.eu) project, the consortium focused on developing tools and producing value-added datasets to maximize the exploitation of the available planetary datasets of the Martian surface. This includes the generation of high quality co-registered DTMs and corresponding terrain-corrected ORIs, using data from different NASA and ESA instruments.

2.1 Acknowledgements

Users are requested to acknowledge the dataset by mentioning it in any relevant figure captions and within acknowledgement within their publications to cite both the DOI of the dataset and the paper describing the processing system, assessment, and mosaic generation:

https://doi.org/10.5270/esa-0j79yk8

The first author of this publication and datasets acknowledges support for her studies from the Indonesian Endowment Fund of Education. This work forms part of the European Union’s Seventh Framework Programme under iMars grant No. 607379 and by the German Space Agency (DLR Bonn), grant 50QM1702 (HRSC on Mars Express). Partial funding was obtained from the STFC "MSSL Consolidated Grant” ST/K000977/1. We also express gratitude to the HRSC team and the MOLA team for the usage of HRSC and MOLA data. In addition, to Marita Wählisch for her kind assistance with the areoid conversion and last but not least, Alexander Dumke for the processing of precise exterior orientation processing results used within this dataset.
3. DATA PRODUCT GENERATION

The dataset is generated using a modified stereo processing pipeline (Kim and Muller, 2019) based on the open-source NASA VICAR (Video Image Communication and Retrieval) software, modified with proprietary software developed at DLR for use with HRSC images (DLR-VICAR) (Scholten et al., 2005). The modification utilizes the Gotcha (Gruen-Otto-Chau) algorithm (Kim and Muller, 2009; Shin and Muller, 2012). This pipeline is illustrated in Figure 1. The pipeline, assessment, and mosaic generation of the dataset are discussed in more detail in Putri, et al., 2019.

Figure 1 Schematic of modified DTM production algorithm based on DLR-VICAR (Kim and Muller, 2009; Putri, et al., 2019)
4. ARCHIVE FORMAT AND CONTENT

4.1 Product Type
A complete set of iMars 3D products for each strip of stereo HRSC images contains the following types of products:

- DTM (MOLA sphere and Mars areoid)
- ORI
- Metadata file

Global mosaics were produced with all 33 DTMs and corresponding ORIs using gdal_merge (https://www.gdal.org/gdal_merge.html). These mosaiced products are also included in this dataset and contain the same type of products.

4.2 Naming Convention
Each set of the iMars 3D product is contained in a directory with a similar naming convention to HRSC level 4. The naming convention for the different types of products listed in (1) is as follow:

- DTM (MOLA sphere): PRODUCT_ID_dt4_ucl.tif
- DTM (areoid): PRODUCT_ID_da4_ucl.tif
- ORI: PRODUCT_ID_nd4_ucl.tif
- DTM (MOLA sphere) mosaic: sprc_mosaic_dtm.tif
- DTM (areoid) mosaic: sprc_mosaic_ori.tif
- Metadata file: PRODUCT_ID_*4_ucl.pvl
- Shapefile: PRODUCT_ID.shp
  PRODUCT_ID.shx
  PRODUCT_ID.dbf
  PRODUCT_ID.prj
  PRODUCT_ID.qpj

4.3 Format Type
- DTM: int16; 1 channel; Geotiff image.
- ORI: byte; 1 channel; Geotiff image.
- Metadata file: ASCII file in PVL format
- Shapefile: GIS-ready (ArcGIS, QGIS, ENVI, etc.) shapefile format

4.4 DTM/ORI Specification
- Projection: Polar Stereographic
- Mars radius reference: MOLA sphere (dt), MOLA aeroid (da)
- DTM resolution: 50m/ pixel
- ORI resolution: 12.5-50m/pixel
- NoData value: -32768 (DTM), 0 (ORI)
4.5 Product Example and Usage

The DTM and ORI file in GeoTiff format can be opened in GIS/image processing software such as ArcGIS, QGIS, and ENVI. Projection and mapping information is embedded in the header of the Geotiff file as well as listed in the PVL metadata file as follows:

Example of gdalinfo output of h2163_0000_nd4_ucl.tif

Driver: GTiff/GeoTIFF
Files: h2163_0000_nd4_ucl.tif
Size is 12344, 22573
Coordinate System is:
PROJCS["STEREGRAPHIC MARS",
  GEOGCS["GCS_MARS",
    DATUM["D_MARS",
      SPHEROID["MARS",3396000,0]],
    PRIMEM["Reference_Meridian",0],
    UNIT["degree",0.0174532925199433]],
  PROJECTION["Stereographic"],
  PARAMETER["latitude_of_origin",-90],
  PARAMETER["central_meridian",0],
  PARAMETER["scale_factor",1],
  PARAMETER["false_easting",0],
  PARAMETER["false_northing",0],
  UNIT["metre",1,
    AUTHORITY["EPSG","9001"]]
Origin = (-429112.500000000000000,711112.500000000000000)
Pixel Size = (25.000000000000000,25.000000000000000)
Metadata:
PRODUCER_DETAILS:https://www.cosmos.esa.int/web/psa/UCL-MSSL_iMars_HRSC_v1.0
  PRODUCER.INSTITUTION_NAME = "University College London"
  PRODUCER.ORGANISATION = "UCL/MSSL"
  PRODUCER.PROCESSING_RESOURCE = "Imaging Group Blades"
  PRODUCER.CONTACT_PERSON = "Alfiah Rizky Diana Putri and Jan-Peter Muller"
  PRODUCER_CONTACT_EMAIL = "alfiah.putri(at)ucl.ac.uk and j.muller@ucl.ac.uk"
  PRODUCT.PROCESSING_DATE = "15 November 2016"
  FILE.EVENT_TYPE=MARS-REGIONAL-MAPPING-G1-La
  HRCAL.RADIANCE_OFFSET=0.0
  HRCAL.RADIANCE_SCALING_FACTOR=0.0688398
HRCAL.REFLECTANCE_SCALING_FACTOR=0.00162757
HRCONVER.ERROR_FRAMES=0
HRCONVER.MISSING_FRAMES=0
HRCONVER.OVERFLOW_FRAMES=0
HRFOOT.BEST_GROUND_SAMPLING_DISTANCE=0.0315
HROTRO.DTM_NAME=h2163_0000_dt4_ucl.vic
HROTRO.EXTORI_FILE_NAME=h2163_0000.nd2.ext_a
HROTRO.GEOMETRIC_CALIB_FILE_NAME=h2gnd_02.cal
HROTRO.SPICE_FILE_NAME=PCK00010.TPC
M94_CAMERAS.MACROPIXEL_SIZE=1
M94_INSTRUMENT.DETECTOR_ID=MEX_HRSC_NADIR
M94_INSTRUMENT.MISSION_PHASE_NAME=MR_Phase_7
M94 ORBIT.START_TIME=2005-09-20T09:13:23.625Z
M94 ORBIT.STOP_TIME=2005-09-20T09:19:37.579Z
PIXEL-SHIFT-BUG=CORRECTED
PRODUCT_TYPE=IMAGE
SPACECRAFT_NAME=MARS EXPRESS

Image Structure Metadata:
INTERLEAVE=BAND

Corner Coordinates:
Upper Left (-429112.500, 711112.500) (31d 6'30.20"W, 76d 3'23.43"S)
Lower Left (-429112.500, 146787.500) (71d 6'56.17"W, 82d21'34.88"S)
Upper Right (-120512.500, 711112.500) (9d37' 6.78"W, 77d52'36.47"S)
Lower Right (-120512.500, 146787.500) (39d23' 9.55"W, 86d47'47.69"S)
Center (-274812.500, 428950.000) (32d38'46.30"W, 81d25'16.22"S)

Band 1 Block=12344x1 Type=Byte, ColorInterp=Gray
NoData Value=0

Example of PVL file h2163_0000_mt4_ucl.pvl

Object = ORI
Object = ProductInfo
Object = Producer
   SoftwareName = "NASA-DLR/VICAR"
   SoftwareVersion = 3.0
   OperatingSystem = "RHEL 6.7"
   ProducerInstitutionName = "University College London"
   ProcessingOrganisation = "UCL/MSSL"
   ProcessingResource = "Imaging Group Blades"
ContactPerson = "Alfiah Rizky Diana Putri"
ContactEmail = "alfiah.putri{at}ucl.ac.uk"
End_Object

Object = Image
  FileName = h2163_0000_nd4_ucl
  Format = GeoTiff
  Lines = 12344
  LineSample = 22573
  Band = 1
  BitDepth = Byte
  DTMResolution = 50
  ORIResolution = 25
  Unit = Metre
  NodataValue = 0
  Projection = "Polar Stereographic"
End_Object

Object = DataProduct
  ID = h2163_0000
    InstrumentHostName = "Mars Express"
    InstrumentHostID = MEX
    TargetName = Mars
    InstrumentName = "High-Resolution Stereo Camera"
    InstrumentID = HRSC
    ProcessingLevel = 4
    ProductTypeName = "Orthorectified Image to HRSC DTMs"
    ProductTypeID = ucl
    DataSetName = "MSSL_iMars_HRSC_V1.0"
    ProcessingDate = "15 November 2016"
End_Object

Object = MapProjection
  MapProjectionType = Equidistant
  ProjectionLatitudeType = Planetocentric
  AAxisRadius = 3396.0
  BAxisRadius = 3396.0
  CAxisRadius = 3396.0
  CoordinateSystemName = Planetocentric
  PositiveLongitudeDirection = East
  KeywordLatitudeType = Planetocentric
  CenterLatitude = -90
CenterLongitude = 0
MapScale = 25
MaximumLatitude = 76.05651
MinimumLatitude = 86.79658
EasternmostLongitude = 350.38145
WesternmostLongitude = 288.88440
End_Object
End_Object

Object = Algorithm
Group = DTMProcessing
  ExtoriFileName=h2163_0000.nd2.ext_a
  GeometricCalibFileName=h2gnd_02.cal
  MacropixelSize=1
  InstrumentDetectorID = "MEX_HRSC_NADIR"
  InstrumentMissionPhaseName = MR_Phase_7
  SpiceFilename=PCK00010.TPC
  SpatialResRatio = 1
End_Group

Group = ZKMatcher
  GaussFilter = 3
  MaximumDisparity = 5
  MinimumDisparity = -5
  DisparityRatio = 4
  ZKIteration = 5
  ZKCorrelation = 0.975
End_Group

Group = GruenMatcher
  GruenRadius = 9
  GruenCorrelation = 0.6
  GruenEigen = 600
End_Group

Group = GeoTiffConversion
  RadianceOffset = 0.0
  RadianceScalingFactor = 0.0688398
  ReflectanceScalingFactor = 0.00162757
  ErrorFrames = 0.0
MissingFrames = 0.0
OverflowFrames = 0.0
BestGroundSamplingDistance = 0.0315
End_Group
End_Object
End_Object
End

In both the GeoTIFF footer tag metadata and the PVL file, information on image, georeferencing, DTM production and conversion to GeoTIFF are available. The PVL metadata has added detail on matcher parameter and producer.
5. KNOWN ISSUES

There are known artefacts present in the HRSC DTMs released. Efforts have been made to try to reduce these artefacts, but looking at the individual colourised_by_height hillshaded relief maps to check whether the Region of Interest is affected is suggested before using the DTM for any quantitative purposes.

<table>
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<tr>
<th>Issue</th>
<th>Explanation</th>
<th>Illustration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Edge jumps</td>
<td>Step artefact caused by higher differences over the edges of DTM strip from the matching procedure in Kim and Muller (2009). Efforts were undertaken to crop the edges of the DTM to exclude the artefacts, but a few pixels may still remain at the edge of the strips.</td>
<td></td>
</tr>
<tr>
<td>Ripples in areoid (DA) products</td>
<td>Concentric lines caused by the rounding of MOLA values used in converting from DT (MOLA sphere) to DA (areoid) products. Efforts were undertaken to remove the artefacts, but some lines may still remain.</td>
<td></td>
</tr>
<tr>
<td>Ripples in H4917_0009</td>
<td>Ripple artefacts occur in H4917_0009</td>
<td></td>
</tr>
</tbody>
</table>
6. SOFTWARE

NASA-VICAR used as the base of this pipeline is released as open source (https://www-mipl.jpl.nasa.gov/vicar_open.html and https://github.com/nasa/VICAR)

It should be noted that it appears possible that you can create your own HRSC DTM + ORI products using the NASA Ames Stereo Pipeline (ASP) available through https://github.com/NeoGeographyToolkit

However, no testing or assessment has been made as to whether you can use this package without the improvements to the exterior orientation files used in this work. A version of ASP called CASP-GO has been developed for processing NASA-MRO CTX and HiRISE data as well as ESA Trace gas Orbiter CaSSIS data which will be released in the near future. We hope that this release will include explicit HRSC functionality.