Magellan GxDR User's Guide
for the PDS4 Dataset
09/15/2023

1.0 Introduction

This document is a quick start guide to the updated PDS4 version of the Magellan GxDR (Global Topography, Emissivity, Reflectivity, and Slope Data Record) archive. This updated GxDR dataset was created by the Planetary Data System's (PDS) Geosciences Node as part of the Node's effort to migrate all its holdings to the PDS4 standard (https://pds.nasa.gov/datastandards/documents/current-version.shtml). The GxDR dataset consists of global maps of four Venus surface parameters derived from the altimetry and radiometry data collected by the Magellan spacecraft. The dataset includes emissivity, radar reflectivity, surface slope, and topography (planetary radius) maps. The maps are provided as Mercator, sinusoidal, and north and south polar stereographic map projections. This new PDS4 GxDR archive contains the same data as the original PDS archive found on volume MG_3002, but with the multiple small framelets of each product put together into a single mosaic. The updated archive also has browse products that can be easily displayed for quick-look views of the maps. This document will help users understand what is in the archive, how it was created, and how it is different from the original dataset.

2.0 Magellan Mission

The Magellan radar mapping mission produced the first global, high-resolution SAR (Synthetic Aperture Radar) images and topographic datasets of Venus. The spacecraft was launched on May 4, 1989. It arrived at Venus on August 10, 1990 and began systematic mapping of the Venus surface on September 15, 1990. The main goals of the Magellan mission were geologic mapping with SAR imaging and determining the topography of Venus, along with mapping surface properties of Venus at microwave (12.6 cm) wavelengths.

Magellan mission operations were divided into several mapping cycles, each being 243 Earth days in duration. This was the time it took Venus to rotate once under Magellan's orbit. The first three mapping cycles concentrated on collecting SAR imaging and altimetry and radiometry data. The fourth and fifth cycles were devoted to mapping the planet's gravity field. The final cycle occurred after the spacecraft orbit was lowered to collect better gravity data near the poles. The mission completed on October 13, 1994 after the spacecraft was commanded to drop into the Venusian atmosphere.

The Magellan spacecraft orbit was elliptical (294 by 8543 km) and nearly polar with an 85.5° inclination. Periapsis was located at about 10° N latitude. The orbit period was 3.25 hours. Data collection occurred on each orbit as the spacecraft traveled from north to south. It started when Magellan passed the North Pole and the High-Gain Antenna (HGA) was pointed toward the Venusian surface. Data collection started after passing the North Pole on each alternate orbit and continued to about 57°S latitude. In the intervening orbits, data collection started at about 70°N and extended to 74°S latitude. The Magellan SAR instrument mapped the surface with a resolution of 120 to 300 meters. On the second part of the orbit when the spacecraft was moving from south to north, the HGA was used to transmit the data to Earth in two sessions before and after apoapsis [Saunders, *et al.*, 1990; Saunders, *et al.*, 1992].

3.0 Altimetry and Radiometry Data

The altimetry and radiometry data used to generate the GxDR maps were collected in between SAR transmit and receive bursts. After the last SAR echo in a burst was received, the system was switched to the altimeter mode that used the horn antenna to transmit a set of seventeen nadir-directed pulses to measure the topography. Once the last altimeter echo was received the system used the HGA for about 50 ms to receive the naturally emitted microwave energy from the planet surface.

The altimeter system was designed to determine the distance between the spacecraft and a footprint on the surface approximately 10 to 30 km in diameter. Knowledge of the spacecraft's orbital position relative to the center of Venus, combined with the spacecraft-to-surface distance derived from the altimeter signals was used to determine the radius of Venus for each footprint. The intensity and time dispersion of the altimeter echoes were used to estimate RMS slopes and Fresnel power reflection coefficients [Ford and Pettengill, 1992; Pettengill *et al.*, 1991].

The HGA was also used with the radar transmitter turned off to measure the passive emissions from the surface at 12.6 cm wavelength. These radiometry measurements had the same geometry (i.e., emission angles) as the SAR data. The radiometry footprint size and emission angle varied with spacecraft altitude and hence latitude [Pettengill *et al.*, 1992].

Table 1: Description of GxDR Surface Parameters

Product Type	Surface Parameter	Document File	Data Type
GEDR	Microwave Emissivity	gedrds.txt	16-bit unsigned integer
GREDR	Radar Reflectivity	gredrds.txt	8-bit unsigned integer
GSDR	Surface Slope	gsdrds.txt	8-bit unsigned integer
GTDR	Planet Radius	gtdrds.txt	16-bit unsigned integer*

* The radius error map data are stored as 8-bit unsigned integers.

The document directory in the GxDR archive has four files that briefly explain how the altimeter and radiometry measurements were used to compute the surface parameters for each of the GxDR map types. Table 1 has a summary of the GxDR map types and the name of the file that describes them. Note that the GTDR maps contain measures of the Venus radius.

4.0 Original GxDR Dataset

The GxDR products were originally stored on magnetic tape by the Magellan project (see the *gxdr_sis.txt* file in the document directory for a description of the tape format). Eventually, the GxDRs were transferred to a CD-ROM for distribution. A copy of this CD-ROM, volume_id MG_3002, is on the Geosciences Node's online repository at:

pds-geosciences.wustl.edu/missions/magellan/gxdr.

This copy was the source for the new PDS4 version of the GxDR dataset.

As noted in the introduction, four different map projections were used to present the surface property data in the GxDR maps: Mercator, Sinusoidal, North Polar Stereographic, and South Polar Stereographic. The Mercator and Sinusoidal maps were divided into 32 framelets each 1024 lines by 1024 samples in size and arranged in four rows and eight columns. The Polar Stereographic maps consist of four framelets each 1024 lines by 1024 samples arranged in two rows and two columns. Dividing the maps into framelets and the size of those framelet reflect the computer and image display systems available at the time of the Magellan mission in the early 1990's.

5.0 PDS4 Archive Organization

The new PDS4 GxDR dataset version was created using the PDS4 standard. This section describes the organization of the dataset according to PDS4 standards. The highest level of organization for a PDS4 dataset is called a ***bundle***. A bundle is a set of one or more related collections that can be of different types. A ***collection*** is a set of one or more related ***basic products***, which are typically all of the same type (e.g., raw, calibrated, or derived data, documents; etc.). Basic products in PDS4 contain one or more digital objects (tables, images, etc.) and their labels. Bundles and collections are logical structures, not necessarily tied to any physical directory structure, although the physical organization of a PDS4 dataset usually follows the bundle and collection structure.

All items in a PDS4 archive are considered products. A PDS4 product consists of a PDS4 label and the item that the label describes, typically one or more files. For example, an image product comprises both the image and the label that describes that image. The exception is a bundle product, which is a single xml file that lists the collections in the bundle. Bundle products can also reference an optional readme file. Each PDS4 product is uniquely identified by a string in its label called a Logical Identifier (or LID). A LID consists of four to six tokens separated by a colon. The first three are fixed for datasets archived by the PDS. These first three are: "urn:nasa:pds". The fourth token is the bundle identifier. In this case the bundle identifier is: "magellan_gxdr". The fifth token is a collection identifier, whereas the sixth token is a product identifier. This formation rule generates a unique LID across all of PDS because the bundle identifier has to be unique across the PDS, the collection identifier has to be unique within the bundle, and finally the product identifier has to be unique within its collection. As an example, the GxDR product LID for the Mercator projection of the emissivity map is:

urn:nasa:pds:magellan_gxdr:data:gedr_merc

The product identifier token is usually based on the product file name without the extension. The file name formation rule for GxDR products is described in the next section.

If there are multiple versions of a PDS4 product these can be distinguished by version identifier (VID), which has the form M.n, with M indicating the major version (starts with 1) and n noting minor version revisions (starts at 0 for each major version). The VID is an attribute listed in the PDS4 label. The LID and the VID can be combined to refer to a specific product version by concatenating the LID and VID with two colons. This is known in PDS4 as a LIDVID. For example, the LIDVID of version 1.0 of the product above would be:

urn:nasa:pds:magellan_gxdr:data:gedr_merc::1.0

The GxDR PDS4 bundle has four collections – data (GxDR maps), browse, document, and miscellaneous. Each collection is described below in more detail.

5.1 Data Collection

The PDS4 GxDR map products are stored in the data collection. The collection identifier is "data" and all GxDR maps are stored in a physical directory named "data" under the bundle root directory. The "data" directory contains the collection product, which is a PDS4 label and a CSV file with an inventory of all products in the collection. The inventory file has two fields. The first field indicates whether the product is a primary or secondary member of the collection. All GxDR products are primary members of the data collection. The second field lists the LIDVID for a product. An example data collection inventory record looks like this:

P, urn:nasa:pds:magellan_gxdr:data:gedr_merc::1.0

There are four subdirectories under the "data" directory. These subdirectories are: "mercator" for the Mercator projection products, "sinusoidal" for the sinusoidal map projection products, "north" for the north polar stereographic products, and "south" for south polar stereographic products.

Each map product consists of three files. There are the image file (*.img), the ENVI header file (*.hdr) for use in reading the data into the commercial ENVI software package, and the PDS4 label (*.xml) that describes both the image file and ENVI header. The file names have the form of:

gxdr_nnnn.ext

where x indicates the type of surface property displayed in the map (e=emissivity, re=reflectivity, s=slope, and t=topography); and nnnn indicates the map projection. An example file name for an image product is:

gedr_merc.img

As noted, the image file name without an extension is used as the product identifier in its LID.

The sinusoidal directory contains a fifth map, which is an estimate of absolute accuracy of the planetary radius values (*gtdr_error.img*). Thus, there are a total of seventeen GxDR maps in the data collection.

5.2 Browse Collection

The browse collection contains a subsampled and contrast-enhanced version of each GxDR map stored as a JPEG image. The collection identifier is "browse". All of the browse products are located in a directory named "browse" under the bundle root directory. The organization of the browse collection is the same as for the data collection in terms of subdirectories. Details on how the browse products were created are given in Section 6.2. The browse products are intended for quick-look reviewing of the maps. Each browse product consists of two files: the JPEG image (*.jpg) and its PDS4 label (*.xml). The PDS4 label for the browse product has a pointer to the LID of the primary mosaic product. The pointer can be found in the Reference_List of the browse label and looks like this:

```
<Reference_List>
  <Internal_Reference>
    <lid_reference>urn:nasa:pds:magellan_gxdr:data:gedr_merc</lid_reference>
    <reference_type>browse_to_data</reference_type>
  </Internal_Reference>
</Reference_List>
```

File names for browse products have the same formation rule as file names for mosaic products with the addition of "_brw" before the file extension. For example:

gedr_merc_brw.jpg

The product identifier for a browse image in the product LID is the browse file name without the extension.

5.3 Document Collection

The document collection contains several types of documentation about the GxDR PDS4 archive. The collection identifier is "document". The document collection includes a series of ASCII text files that were derived from the PDS catalog files found on the original CD-ROM. These files describe the Magellan mission, the spacecraft, the radar instrument, and the four data product types. This documentation was largely written in the 1990s by Magellan project personnel and science team members. See Table 1 for the file names of the files that describe GxDR maps. The document collection also includes the Magellan GxDR SIS (Software Interface Specification) document (Ford, 1991) that describes GxDR format as the data were stored on magnetic tape (file name *gxdr_sis.txt*). In addition, it describes the map projections used for GxDRs.

This user's guide is also located in the document collection as a PDF file. Each document product in this collection is accompanied by a PDS4 XML label. The label has the same base name of the document it describes, but with an extension of *.xml.

5.4 Miscellaneous Collection

A miscellaneous collection in PDS4 contains supplementary information useful in the interpretation and use of the data in the bundle. The miscellaneous collection of the GxDR bundle has a catalog of GxDR PDS4 products containing metadata about the GxDR maps. The file name is *gxdr_catalog.csv*. The metadata in this catalog has the product type, map projection, and the latitude and longitude bounding box for each GxDR map. It is intended to help users quickly look through the dataset to find products of interest.

6.0 Detailed Data Product Descriptions

The subsections describe how the new PDS4 versions of the GxDR maps were generated, their structure, and their PDS4 labels.

6.1 GxDR Maps

As noted the original GxDR products were divided into a series of framelets, each 1024 lines by 1024 samples in size. For the non-polar GxDRs there are 32 framelets arranged in four rows and eight columns. The framelets are arranged in a row-major order. The first framelet is located in the upper-left corner of the map; the second is to the right of that, and so forth. Framelet number 32 is in the lower-right corner. Each map was reassembled by simply reading the framelets into a blank array without any geometric adjustments. Reconstructed non-polar GxDR products are 4096 lines by 8192 samples. Pixel values are stored either as 16-bit or 8-bit integer values (Table 1). All maps are projected at a scale of about 4641 meters/pixel.

The polar projected GxDRs were divided into four framelets, arranged into a two by two array. Polar framelets also are 1024 lines and 1024 samples. Thus, each reconstructed polar map has 2048 lines and 2048 samples. The polar maps were reassembled in the same manner as the non-polar maps.

Every GxDR image file is supported by two separate ancillary files. One is an ENVI header file (*.hdr). ENVI is a commercial image processing package that is widely used by researchers. The ENVI header file is an ASCII file that contains a number of parameters, such as image size in lines and samples and data type, which allows the software to read and display the mosaics. It also contains map projection information so that ENVI can convert pixel locations into latitude and longitude position on the planet.

The other ancillary file is the PDS4 label written as an XML document. It has the same base name as the image file, but with a file extension of *.xml. The PDS4 label is broken up into a number of sections. The first is the identification area, which contains the product LID, a title for the product, and the version of PDS4 standards that were used to construct the label. The next section contains pertinent metadata that can be used to support search tools, image display, and data analysis. Details about the map projection are described in a separate label section using the PDS4 cartography dictionary. The File_Area_Observational section of the label describes the physical structure of the image file, such as the data type and the number lines and samples in the mosaic. It also contains unit, scaling-factor and value-offset parameters that can be used to convert the stored value into a physical unit value (Table 2). The last section has a pointer to the ENVI header file.

Table 2: Scale and Offset Values

Product Type	Map Parameter	Scaling Factor	Value Offset	Unit
GEDR	Emissivity	0.0001	-0.0001	unitless
GREDR	Reflectivity	0.005	-0.005	unitless
GSDR	Slope	0.1	-0.1	degree
GTDR	Radius	1.0	6039999.0	meter
Radius Error	Error	5.0	-5.0	meter
observed_value = (stored_value * scaling_factor) + value_offset				

Several validation steps were done to ensure the quality control of the reconstructed maps. Each GxDR map on the original CD-ROMs has a binary file named *hist.tab*, which contains a histogram of the complete map. The histogram file lists the number of pixels in the map that occur for each stored value (DN) in the map. These data were used as a quality control check by comparing the histogram of the reconstructed map with the values in the *hist.tab* file. Checks were also done by displaying the reconstructed maps in ENVI and the PDS4 data viewing tool. Latitude and longitude location information was also spot-checked when the map was displayed in ENVI.

6.2 Browse Products

A browse version of each map was generated to provide a quick-look product that can be used to scan through the collection of maps. The browse products were created by first subsampling a map by averaging the pixel values in the each two x two array from the map. Each resulting non-polar browse products contain 2048 lines and 4096 samples. Polar projection browse products are 1024 lines by 1024 samples. A linear contrast stretch was then applied to the subsampled browse image. The browse images are stored with JPEG compression to further reduce the browse file size and for easy display.

Each browse JPEG image file is accompanied by a PDS4 label as a separate XML file. The label has the same base name as the browse image, but with an extension of *.xml. The browse label is similar to the label for the mosaic product, but simpler. It contains the basic identifying information standard to all PDS4 labels and information on the physical structure of the browse file, in this case noting that it is a JPEG file. The label also has a pointer to the full-resolution map product.

7.0 Map Projections

There are three map projections used in the Magellan GxDR dataset: Mercator, sinusoidal, and polar stereographic. The subsections below describe the details of each projection type. Each projection uses a spherical model for Venus with a radius of 6051.0 km. East longitudes are positive. Note that the PDS4 map projection parameters assume that whole number values of line and sample correspond to the center of a pixel. For example, the center of the upper-left corner pixel has coordinate values of 1.0 for both line and sample, whereas, the upper-left corner of this pixel has coordinate values of 0.5 for both line and sample.

Equations for converting latitude and longitude to pixel location are given in section 5.4 of the *gxdr_sis.txt* file in the document collection, along with assumptions used in these equations.

7.1 Sinusoidal Projection

The sinusoidal projection is an equal-area projection. In the sinusoidal projection, lines of latitude are equally-spaced, straight lines. The central longitude is also straight, but all other lines of longitude are convexly curved, with the spacing between lines of longitude decreasing away from the equator. The spacing between longitude lines scales with the cosine of latitude, so they converge to a point at the poles. The center latitude of all Magellan GxDR sinusoidal maps is 0°. The center longitude is also 0° E for all sinusoidal maps. Sinusoidal-projected maps cover 360° of longitude and extend from -90° to +90° latitude.

7.2 Mercator Projection

In a Mercator projection lines of latitude and longitude are straight lines. Longitude lines are equally spaced, whereas the latitude spacing increases away from the equator. The latitude spacing increases to infinity at the poles. As a result Mercator projected maps usually extend from the equator to mid-latitudes. Latitude limits for the GxDR Mercator projected maps are approximately +/- 66.5°. The center latitude of the GxDR Mercator projections is 0°. The center longitude for the GxDR Mercator projections is 60° east. Note that this center longitude is different from the sinusoidal maps.

7.3 Polar Stereographic Projection

The Venus north and south polar areas in the GxDR dataset are presented in polar stereographic map projections. In the polar stereographic projection, the projection is centered on either the North or South Pole. Lines of longitude extend radially out from the center and lines of latitude are concentric circles around the center. The center longitude of the polar maps is 90° east and extends straight down from the map center. Longitude 180° east extends to the right. The polar projections cover 360° of longitude. Latitudes extend to about +/- 31.91° based on the corners of the maps.

8.0 Caveats

The following notes about the reflectivity maps came from the original GxDR CD-ROM.

```
A systematic error of (currently) unknown origin appears to have
corrupted the reflectivity values derived from altimeter data. This
error leads to an apparent increase in radar reflectivity with
latitude, so that the average values in polar regions are more than
double those in equatorial regions. The increase is not believed to
be real since it has not been observed in prior experiments, nor in
the Magellan radiometry experiment, where it would have led to a
decrease in emissivity at high latitudes, instead of the modest
increase that was observed.

The Sinusoidal projection of the GREDR has not been compensated in
any way, but the Mercator and two polar projections have been corrected
with a "flat fielding" algorithm to attempt to remove the latitudinal
bias.

The radar reflectivity rho' is computed from the sum of two
factors, rho derived from the strength of altimetry echoes, and
rhocor, a correction due to diffuse scattering that is derived from
the SAR backscatter cross-section. These parameters were taken from
the ar_rho and ar_rhocor fields of altimetry data files in the
ARCDR product. To compensate for the latitudinal error, all rho
values were multiplied by an 8th order latitude-dependent polynomial

  rho' = rho*(p0+x*(p1+x*(p2+x*(p3+...))))/p0 + rhocor

where x = (lat-lat0)/90, lat0 = periapsis latitude (~10N), and

     p0 =  0.110826    p1 = -0.0135412    p2 = -0.241179
     p3 = -0.0103096   p4 =  1.55816      p5 = -0.130031
     p6 = -2.08811     p7 =  0.242347     p8 =  0.962462

The polynomial coefficients p0 through p8 have been adjusted to
retain the same average rho at all latitudes, ignoring areas known
to possess anomalous reflectivity (Maxwell Montes, Beta Regio, and
Aphrodite Terra).
```

9.0 References

Ford, P. G., 1991, Global Altimetry and Radiometry Data Record, Project Magellan Software Interface Specification Document MIT-MGN- GxDR, Version 2.3, 40p. (Included in this bundle)

Ford, P. G. and G. H. Pettengill, 1992, Venus Topography and Kilometer-Scale Slopes, *JGR, 97*, 13,103-13,114, https://doi.org/10.1029/92JE01085.

Pettengill, G. H., P. G. Ford, W. T. K. Johnson, R. K. Raney, and L. A. Soderblom, 1991, Magellan: Radar Performance and Data Products, *Science, 252*, 260-265.

Pettengill, G. H., P. G. Ford, and R. J. Wilt, 1992, Venus Surface Radiothermal Emission as Observed by Magellan, *JGR, 97*, 13,091-13,102.

Saunders, R. S., *et al.*, 1992, Magellan Mission Summary, *JGR, 97*, 13,067-13,090.

Saunders, R. S., G. H. Pettengill, R. E. Arvidson, W. L. Sjogren, W. T. K. Johnson, and L. Pieri, 1900, The Magellan Venus Radar Mapping Mission, *JGR, 95*, 8339-8355.