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VENUS EXPRESS/VMC NIR2 NIGHTSIDE RE-CALIBRATED IMAGES AND SEGMENTED MAP OF RELATIVE VENUS SURFACE EMISSIVITY PRODUCT USER GUIDE

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1 Introduction

1.1 Executive Summary

The objectives of the activity were to recalibrate the VMC near-IR nightside data set (using improved flat-fielding) and then to derive a global map of surface relative emissivity at 1 µm for the northern hemisphere and equatorial region of Venus using advanced data processing and radiative transfer modelling algorithms. The VMC data were re-calibrated and a 9-segment surface relative emissivity map was obtained.

1.2 Purpose and scope

The purpose of this **VEX-VMC-MPS-NIR2-NS-RCI-EMI_SGMNT-GSF-PUG** document (Venus Express (VEX), Venus Monitoring Camera (VMC), Max Planck Institute for Solar System Research (MPS), Near Infrared 2 (NIR2), Nightside (NS), Re-Calibrated Images (RCI), segmented map (SGMNT) of relative Venus surface emissivity (EMI), Product User Guide (PUG)) is to provide users with the description of the recalibrated VMC NIR2 images and 9-segment map of relative surface emissivity, product naming and format. Scientific details of how the data were derived, as well as a description of the image metadata, see in [11]. It is the official interface between the VMC team and the Guest Storage Facility [3].

1.3 Archiving Authorities

The Guest Storage Facility [3], developed in 2019 by ESA PSA, is an FTP file repository into which scientists from the planetary community can upload and share scientific products valuable for the community.

1.4 Intended Readership

The staff of the archiving authority (Planetary Science Archive, ESA, RSSD, design team) and any potential user of the VMC/VEx data.

1.5 Relationships to Other Interfaces

This document is in close relationship to

- EGSF-DDICD-VEX-VMC-MPS-NIR2-NS-RCI-EMI_SGMNT [11]
- Experimenter to (Science) Archive Interface Control Document (EAICD) [7]
- VenusExpress - VMC Data Products Naming Convention [10]
- VenusExpress - VMC Level-1 Product Description [8]
- VenusExpress - VMC Level-2 Product Description [9]
- PDS3 Standards Reference [5]
- Planetary Science Data Dictionary [6]

1.6 Contact Names and Addresses

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1.7 Acronyms

Akatsuki *Akatsuki*. 6

EnVision *EnVision*. 6

MGN *Magellan Venus Radar Mapping Mission*. 6

CCD A Charge-Coupled Device. 6

DNs Digital Numbers. 6

ESA European Space Agency. 5

GSF Guest Storage Facility. 6

MPS Max-Planck-Institute for Solar System Research, Göttingen. 5

NIR Near Infra-red. 6

VEx *Venus Express*. 6

VIRTIS Visible and Infra-Red Infra-Red Thermal Imaging Spectrometer. 6

VMC Venus Monitoring Camera. 6, 7, 11, 12

2 Scientific background and motivation

Venus and Earth are thought to have formed in similar environments, but divergent evolutionary paths lead to extreme differences in conditions on these sister planets. Why and how did these planet-twins become "antipodes"? This question is one of the most fundamental in planetary science [1]. Evolution of planetary interiors and atmospheric conditions leave footprints on planetary surfaces. Conventional imaging of the Venus surface is hindered by the thick atmosphere and clouds. They block radiation emitted by the surface almost in the entire electromagnetic spectrum, leaving only radio and microwave ranges in which the atmosphere is completely transparent, and several narrow spectral transparency "windows" in the Near Infra-red (NIR) range, where atmospheric absorption is weak and radiation from the surface can leak to space. The NIR thermal emission bears information about the surface temperature and mineralogical composition of the top few hundreds of microns of the surface that are subject to strong changes due to evolutionary processes, e.g. weathering, cratering, etc. The emission measured from orbit also depends on the atmospheric properties and, in particular, cloud opacity.

The *Venus Express* (VEx) spacecraft [15] that operated in orbit around Venus from 2006 through 2014 carried two instruments capable of imaging in the NIR: the Visible and Infra-Red Infra-Red Thermal Imaging Spectrometer (VIRTIS) (Piccioni et al., 2006) and the Venus Monitoring Camera (VMC) [4] (see fig. 2.1). Together they provided the first systematic thermal mapping of the Venus surface from orbit. VIRTIS mapped the southern hemisphere while VMC observed equatorial regions and the northern hemisphere fig. 2.2 thus delivering complimentary data sets. Spatial resolution on the surface of such observations is limited by the blurring effect of the atmosphere and is not better than $50\,\mathrm{km\,pix^{-1}}$.

VMC captured around 10,000 images of the Venus night side thus having delivered the most extensive data set to date. The first analysis focused on retrieval of the surface and atmospheric properties from individual orbits (*e.g.* [2, 13, 12]). This analysis led to the discovery of ongoing volcanic activity event on Venus in the Ganis Chasma. However, not all VMC data were used in those works due to calibration issues related to the detector damage during the cruise phase [14, 16].

VMC data set calibration problems It was realized that further refinement of the calibration is necessary in order to make the whole VMC surface data set suitable for photometric studies. The gained experience in the image processing and analysis allows us to create a high-level data set of relative surface emissivity, which would be complimentary to already published *Magellan Venus Radar Mapping Mission* (*MGN*) and VIRTIS data sets, and *Akatsuki* (*Akatsuki*) data and *EnVision* (*EnVision*) mission in the near future. This would prepare the VMC surface data for the comprehensive usage by the scientific community.

The in-flight damage of the VMC A Charge-Coupled Device (CCD) required additional correction (flat fielding) of the images using featureless images of the Venus polar clouds assuming their uniform brightness. Another issue is that the VMC laboratory calibration is valid for exposures shorter than 4 s, while surface images were taken with the longest exposure of 30s. Both calibration uncertainties manifest themselves as inconsistent brightness values in overlapping images (fig. 2.3).

This work propose an advanced image processing to minimizing brightness differences between overlapping images. The adjustment was done automatically by fitting the flat fields for each orbit by a smooth function minimising squared deviation between registered brightness in consecutive images for the same regions. 542 out of 622 VMC night side orbits were successfully corrected, decreasing the image-to-image discontinuity under normal conditions to $1.5\,\%$ or less (the typical signal range in VMC surface images is 100 – 150 Digital Numbers (DNs). 80 orbits were not suitable for this type of processing because area of image intersections is too small or absent. Details could be found in [11]. The corrected VMC images were used to make maps of the surface relative emissivity at $1\,\mu\mathrm{m}$. Retrieved data set are available to the scientific community via Guest Storage Facility (GSF) [3].

Mapping the relative surface emissivity The derived map of relative surface emissivity at $1\,\mu\mathrm{m}$ and its variance may be used for science analysis. The statistical component of the map would allow determination of significance level of the emissivity variations. Spatial distribution of these properties across geological units would provide insights in their mineralogical composition, evolution of the interiors (via properties of the extruded material), weathering processes, dust distribution and transport, and to identify possible active volcanic events. The topmost surface layer which is observable in the

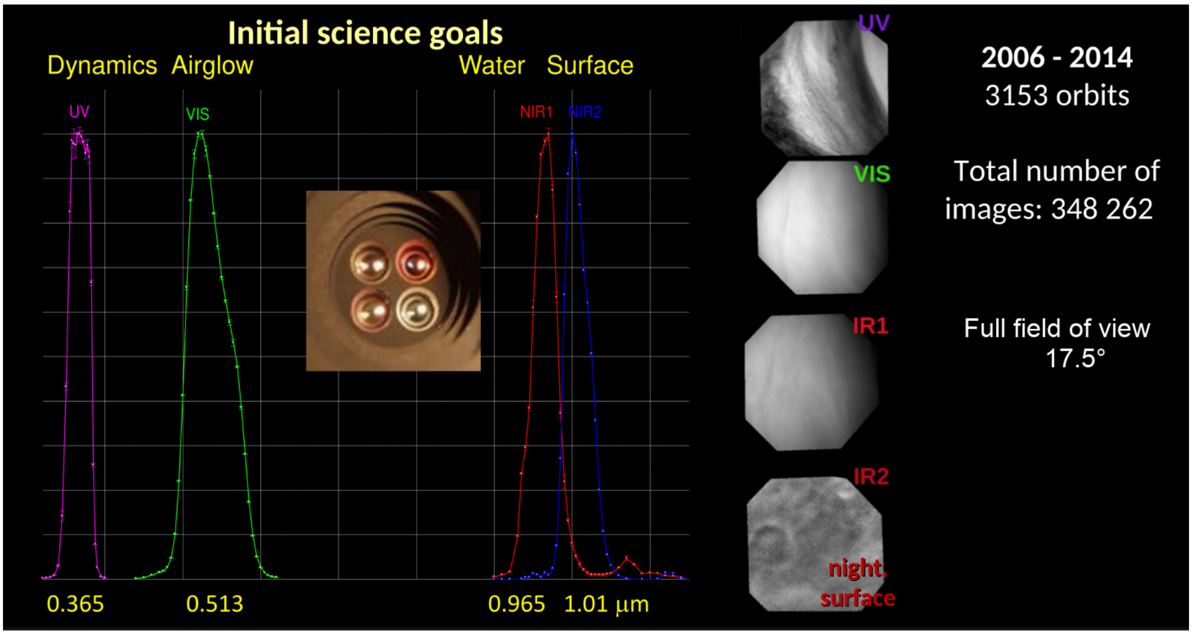
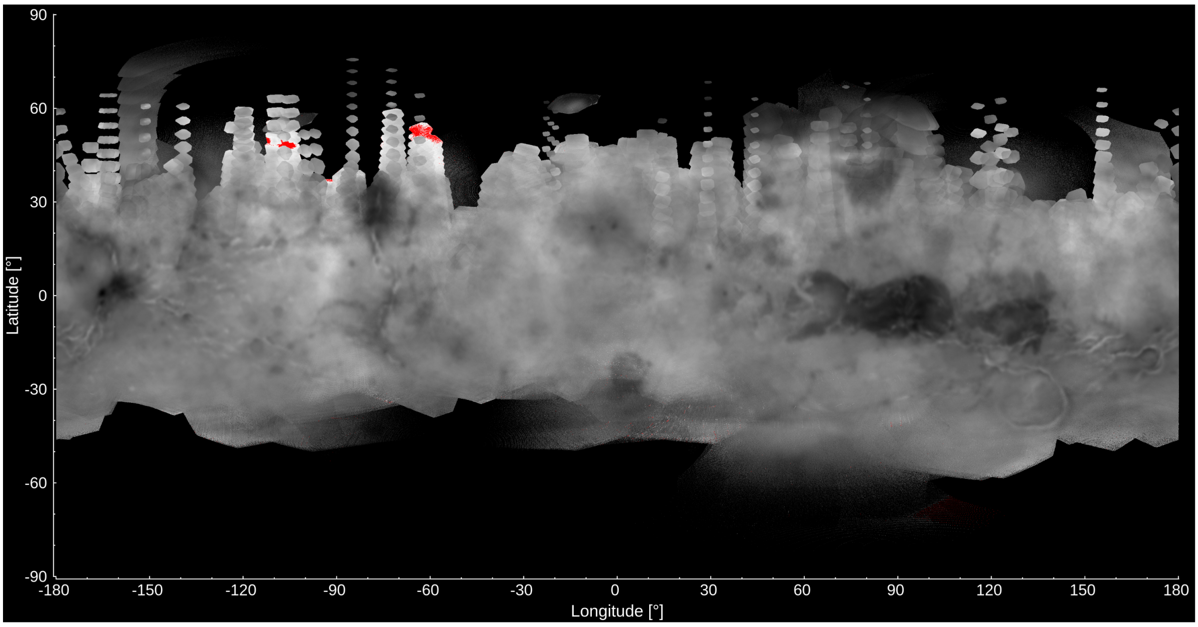
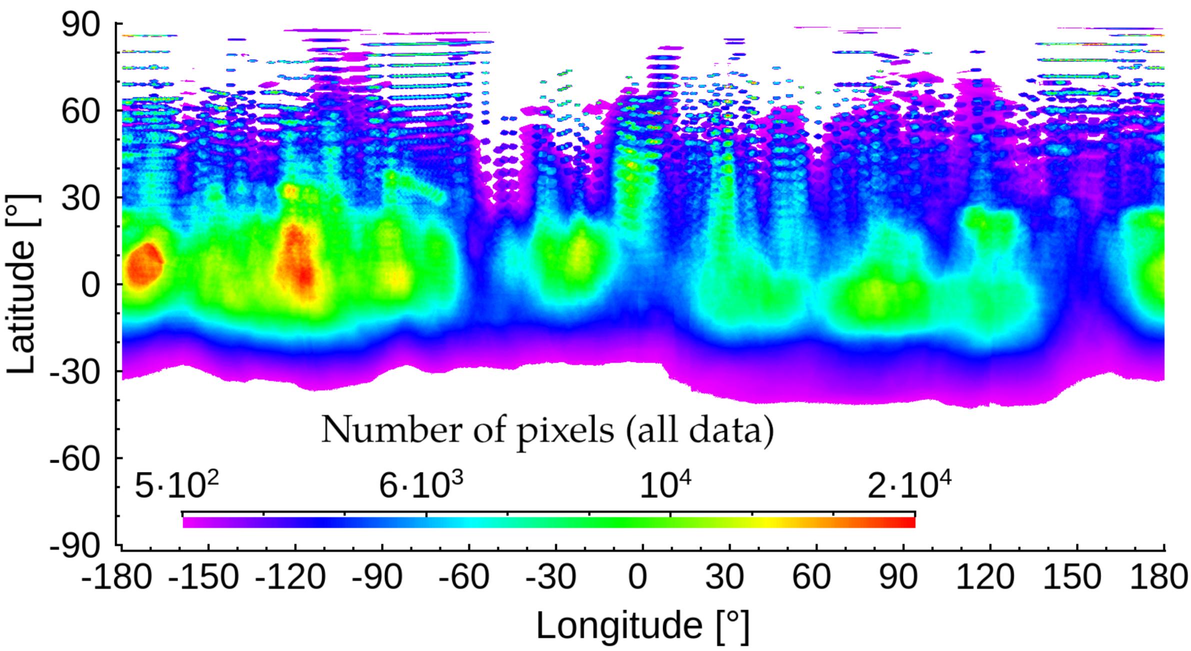


Figure 2.1: Venus Monitoring Camera

near-IR range is expected to evolve quickly enough due to chemical weathering. Thus the VMC emissivity map could also be used as a reference for comparison with future observations.



(a) Joined mosaic



(b) Number of VMC pixels in 0.25° × 0.25° bins.

Figure 2.2: Mosaic composed of all VMC near-IR images on the night side. Bright areas correspond to lowlands that have higher temperature than the mountain regions (dark spots). Circular structures, coronae, are well visible in the lower right of the mosaic below large dark region, Aphrodite Terra

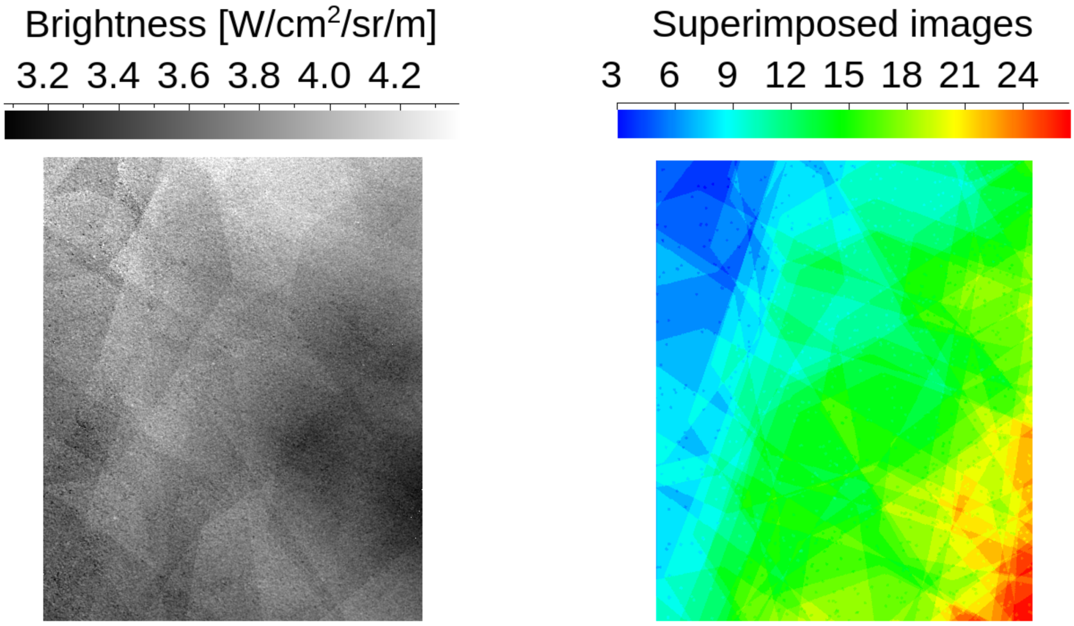


Figure 2.3: VMC mosaic for region 31°N – 39°N and 21°E – 29°E. Straight lines are borders of the individual VMC images

3 Re-calibrated NIR2 surface images

For the surface images taken in the NIR2 filter (n22 filename suffix) an additional processing level is available. These data are obtained from data level 2 images (VMC data archive) applying a procedure to compensate for incorrect additional flat-fielding done in level 2.

All source images for this level were processed by DLR, and the information suitable for previous levels of processing is actual for the current data set.

3.1 Correcting the flat fielding

When additional flat-fielding was performed during the mission, two incorrect assumption were made:

1. The laboratory flat field for NIR2 with 30 s exposures correctly corrects for first-order gradient across the field of view.
2. The only purpose of the additional flat field is to correct for local artifacts.

However, the first assumption turned out to be incorrect and thus the second one made no sense anymore. To correct the images, yet another flat field was computed for each orbit. This second additional flat field is a first order gradient, computed to minimise image-to-image deviation in surface mosaics. Detailed description of the procedure can be found in EGSF-DDICD-VEX-VMC-MPS-NIR2-NS-RCI-EMI_SGMNT.pdf [11].

3.2 Data format and naming

The current dataset ID is "VEX-V-VMC-3-RDR-SCP-V1.0", where SCP = Surface and Cloud Properties (the name of the ESA granted project), 3 indicating the processing level of VMC data (3-RDR). The data set splitted to match the mission extensions, so the above dataset ID would be for the nominal mission phase, and, as example, "EX-V-VMC-3-RDR-SCP-EXT1-V1.0" is for mission extension 1.

VEX mission phases:

Mission Phase	Dates	Orbit numbers
Nominal	2005-11-05 – 2007-10-02	0 to 529
EXT1	2007-10-03 – 2009-05-30	530 to 1135
EXT2	2009-05-31 – 2010-08-21	1136 to 1583
EXT3	2010-08-22 – 2012-12-31	1584 to 2446
EXT4	2013-01-01 – 2014-11-27 (EOM)	2447 to 3153

The data set consists of images in the PDS3 format (image files are uncompressed pixel arrays with attached labels in the PDS3 format) in files with the ".img" extension, in-line with the format and naming of the historical Venus Express VMC data archive in the ESA Planetary Science Archive (PSA). The files can be read by any PDS3 compatible viewer (e.g. NASAView). Description of the metadata could be found in the standard documentation, *e.g.* the PDS objects and attributes used are fully compliant with the definitions given in the PDS3 reference (Appendices A and B in [5]) and the Planetary Science Data Dictionary [6], and some details can also be found in [11] and [7].

4 Segmented relative surface emissivity map at $1\ \mu m$

4.1 Input data

All source images were processed by DLR and then additionally processed (additional flat field accounting) as a part of deliverables of ESA contract 4000126833/18/NL/IB/gg (see chapter 3). General information suitable for previous levels of processing is actual for the current data set (see [7] and [11]).

4.2 General algorithm of relative emissivity map retrieval

We settled at 9-segment map, all segments are of the same longitudinal range ($40°$). We found no strong reason to put segment border at certain location, and therefore the first one begins at $0°$. There is no overlap between the segments. While VMC surface observations extends from (almost) the north pole down to $60°$ south (and sometimes even lower than that), there are no much data to the south from $50°$S and observations at high north latitudes are made at such low altitude and high spacecraft speed that blurring, caused by that, greatly complicates analysis. Thus, the segments cover the latitude range from $50°$S to $60°$N.

The map segments were computed in the following way:

1. For each VMC orbit with surface observations we make a mosaic, consisting of all images from that orbit.
2. For each segment we create a list of VMC orbits that intersect with the segment.
3. Orbital-wise mosaic from each intersecting orbit is projected into the segment geometry, thus bringing all the segment orbits into the same geometry.
4. A map of reference area is projected into the segment geometry as well, and a mask image is created.
5. Mosaics, whose intersection with the reference area is smaller than 0.1 of the total mosaic area, are rejected.
6. For each VMC orbital mosaic we find a factor that withing the non-masked parts of the VMC mosaics (*i.e.* images of the reference region) make the average brightness identical. The found set of factors are applied then to the whole orbital mosaics. This action follows from two assumptions we have to make: average emissivity in the reference region is constant for any reasonably large subset of the reference region, and that we neglect cloud inhomogeneity.
7. All the orbital mosaics are averaged.
8. An emissivity map is computed from the average VMC mosaic.
9. To estimate emissivity retrieval error, the emissivity map is computed from each individual orbital mosaic.

Scientific details of how the data were derived see in [11].

4.3 Data format and naming

The current dataset ID is "VMC-NIR2-EMI_SGMNT-SCP", where SCP = Surface and Cloud Properties (the name of the ESA granted project). Due to the complexities of the data and the capabilities of the used algorithm, the emissivity map consists of nine equal segments with the step by longitude $40°$ (see table 4.1).

Table 4.1: Segments

Segment number	Longitude, degrees
0	000–040
1	040–080
2	080–120
3	120–160
4	160–200
5	200–240
6	240–280
7	280–320
8	320–360

An example of a file naming:

- segment_0_000_040_vmc.img
- segment_0_000_040_stddev_vmc.img
- segment_0_000_040_stddev_norm_vmc.img
- segment_0_000_040_emi.img
- segment_0_000_040_stddev_emi.img

The meaning of the suffixes:

_vmc.img Averaged VMC brightness for the given region.

_stddev_vmc.img The standard deviation of the brightness, computed for the sample of all VMC images for the region.

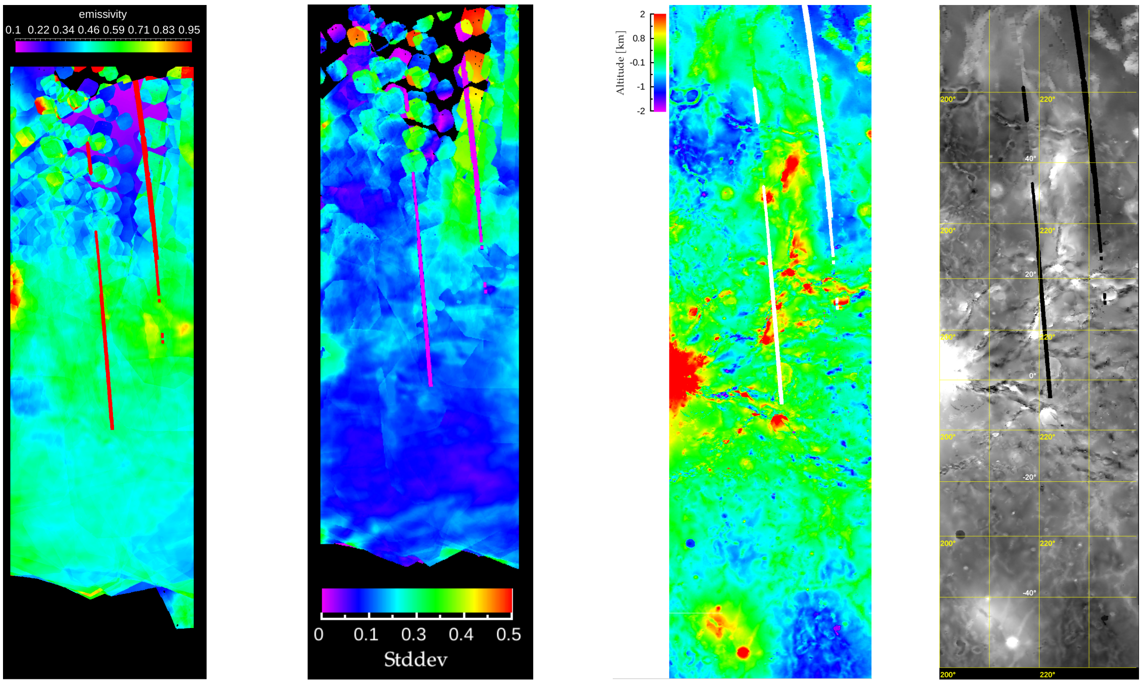
_stddev_norm_vmc.img Normalized standard deviation (coefficient of variation) computed from the standard deviation and average brightness.

_emi.img 1-µm emissivty, derived from the averaged VMC data for the given region.

_stddev_emi.img The standard deviation of the emissivity, computed for the sample of emissivity maps, computed from all individual VMC images for the region.

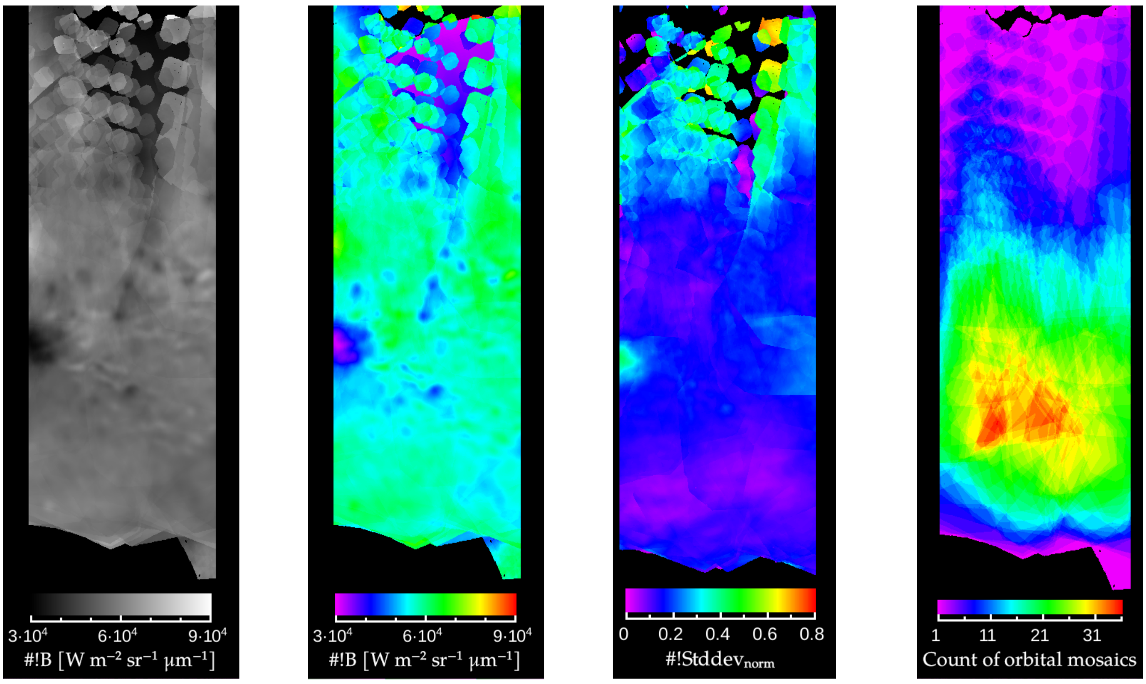
The data set consists of images in the PDS3 format (image files are uncompressed pixel arrays with attached labels in the PDS3 format) in files with the ".img" extension, in-line with the format and naming of the historical Venus Express VMC data archive in the ESA Planetary Science Archive (PSA). The files can be read by any PDS3 compatible viewer (e.g. NASAView). Description of the metadata could be found in the standard documentation, *e.g.* the PDS objects and attributes used are fully compliant with the definitions given in the PDS3 reference (Appendices A and B in [5]) and the Planetary Science Data Dictionary [6], and some details can also be found in [11] and [7].

Example of the produced emissivity map for segment 5 (longitudes $200°$ to $240°$E) and additional information are presented in fig. 4.1 and fig. 4.2.



(a) Emissivity (b) Std dev norm (c) Magellan altimetry (d) Magellan altimetry

Figure 4.1: Segment 5: Longitude 200-240 degrees. a relative emissivity map; b standard deviation; c Magellan altimetry (colour); d same as c but in gray scale



(a) B corrected (b) B corrected (c) B Stddev norm (d) B Count of orbits

Figure 4.2: Example of segment data: segment 5, Longitude 200-240 degrees. Brightness distribution a in gray and b in colour scale, and statistical information: c standard deviation; d count of orbital mosaic

5 Acknowledgements

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6 Applicable Documents

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