CHAPTER 6

Instrument Data and Data Processing

Geological and geomorphological analysis and interpretation of confined areas on Mars usually require a full processing of available image and topographic data found in the study area. In very few cases only – and with several limitations – a completely processed dataset is available ready for out-of-the-box interpretations. The following sections will cover basic data processing environments and software tools used for data processing for this work. General information and characteristics of instrument data and processing is summarized in section 6.3. General data-analysis methods are described in chapter 7. In-depth descriptions of special treatment of data is described in the context of applied analyses and is summarized in the appropriate sections in part III of this work.

6.1. General Overview

Basic processing steps that are undertaken prior to any analysis attempts comprise [1] search of adequate datasets at various internet (WWW/FTP) locations or CD/DVD data mirrors, [2] selection of processable and expressive data, [3] processing of individual images and combining these for image mosaics using various software environments, [4] conversion and adjustments of different datasets so that they fit specific analysis needs and fit to a common reference system, and finally [5] combining all these datasets in an software environment allowing data interpretation, such as a GIS (see figure 6.1).

Manual interaction during image and image-mosaic generation is required as external-orientation data vary in quality from instrument to instrument. In contrast to many freely available terrestrial remote-sensing datasets which are uniformly defined above their reference body and normally make use of clearly defined reference dates, data of Mars consist not only of different file formats but are also connected to various body references. Since the days of Viking about 11 reference systems have been proposed and used, each of them vary in terms of body radii, location of zero longitude, and definition of latitudes, i.e., planetocentric or planetographic latitudes (Table 6.1). The first representation is usually not used for terrestrial data sets in which planetographic latitudes are the standard (see chapter 7.1 for more details on this topic).

Central data servers offering processed and co-registered data like in the case of various US servers, e.g, the Global Land Cover Facility in Maryland, US (GLCF), do not exist for planetary-exploration data.

] Web-based Geographic Information Systems (WebGIS) do however offer certain (mostly proprietary, e.g., *Michael et al.* (2006)) datasets which are pre-combined with other instruments' data but suffer from limitations in terms of image quality or map projections. USGS's freely available *Planetary Interactive GIS on the Web Analyzable Database (PIGWAD)* developments represent the currently best elaborated online information systems which also offers analyzing functionalities (*Hare and Tanaka*, 1999, 2002,

Table 6.1.: Cartographic reference frames for data used in this work, information from PDS and referenced documents cited therein; W_0 refers to the definition of the prime meridian. Latitudes are defined as either planetographic [g] or planetocentric [c].

definition	a-axis [km]	c-axis [km]	W_0 [°E]	datasets
MDIM-1	3393.40	3375.73	176.6460	Viking MDIM 1 [g] and derived maps
MDIM-2	3396.00	3376.80	176.7215	Viking MDIM 2.0 [g] and derived maps
IAU-91	3397.00	3375.00	176.8680	MOLA [c], old
IAU-94	3397.00	3375.00	176.9010	TES [c], MOC (g)
IAU-2000	3396.19	3376.20	176.6300	HRSC [g], THEMIS [c], HiRISE [c], MDIM 2.1 [c]
MOLA	3396.00	3396.00	176.6300	MOLA version L [c]

2003). A few other web-based applications are currently in development which allow fusion of multi-mission datasets (e.g., *Gorelick et al.*, 2003; *Weiss-Malik et al.*, 2005).

6.2. Data Processing Packages and Tailored Software

Data processing starting with compressed raw and unregistered data is mainly performed using two different software systems which are concurring to a certain degree but – in certain aspects – complementary to each other. These software systems are (a) the freely available *Integrated Software for Imagers and Spectrometers (ISIS)* system developed and supported by the USGS Astrogeology Program (AP) (*Gaddis et al.*, 1997; *Torson and Becker*, 1997; *Eliason et al.*, 2001) since the early 1990s, and (b) the *Video Image Communication and Retrieval (VICAR)* software package which is developed, administered and distributed upon requests by NASA/JPL under special licensing conditions.

Both systems are based upon numerous UNIX/VMS-based command-line routines and software modules which have been steadily growing since the late 60s and which are developed around a core system handling data I/O and basic image and data handling routines. The modular approach of these software packages allow users to develop their own applications, make them system-wide available or have them incorporated in future official software releases. Both systems have basic command-line driven pseudo-GUI capabilities which are implemented using the Transportable Application Environment (TAE) although real GUI functionalities are realized only within the USGS ISIS 3 environment by using native window managing libraries.

While new instrument- and mission specific software implementations are found early in the ISIS environment, the VICAR package, developed and supported at the *Multimission Image Processing Laboratory (MIPL)/Jet Propulsion Laboratory (JPL)*, is not an open and officially distributed package released among the public on a frequent and up-to-date term (*Anderson and Mann*, 1989; *Hockey and Barnet*, 1994). HRSC data processing functionalities have been incorporated in the ISIS environment by the USGS starting in 2003 and were made available to interested users contemporary to the first HRSC image releases. More sophisticated data processing methods are implemented around the VICAR core system and forms proprietary software developed at the German Aerospace Center (DLR); the software is not made freely available except under special conditions for members of the HRSC team. The general approach of image and spectral-data processing within both software systems remain identical to the end-user in many aspects. Major confusions are caused in respect to naming conventions regarding the processing level of image data, where ISIS sticks to the Level 0-2 nomenclature commonly adopted in terrestrial systems whereas the VICAR environment makes use of a Level-0 to Level-3 convention but also has numbering schemes that go beyond that in order to designate

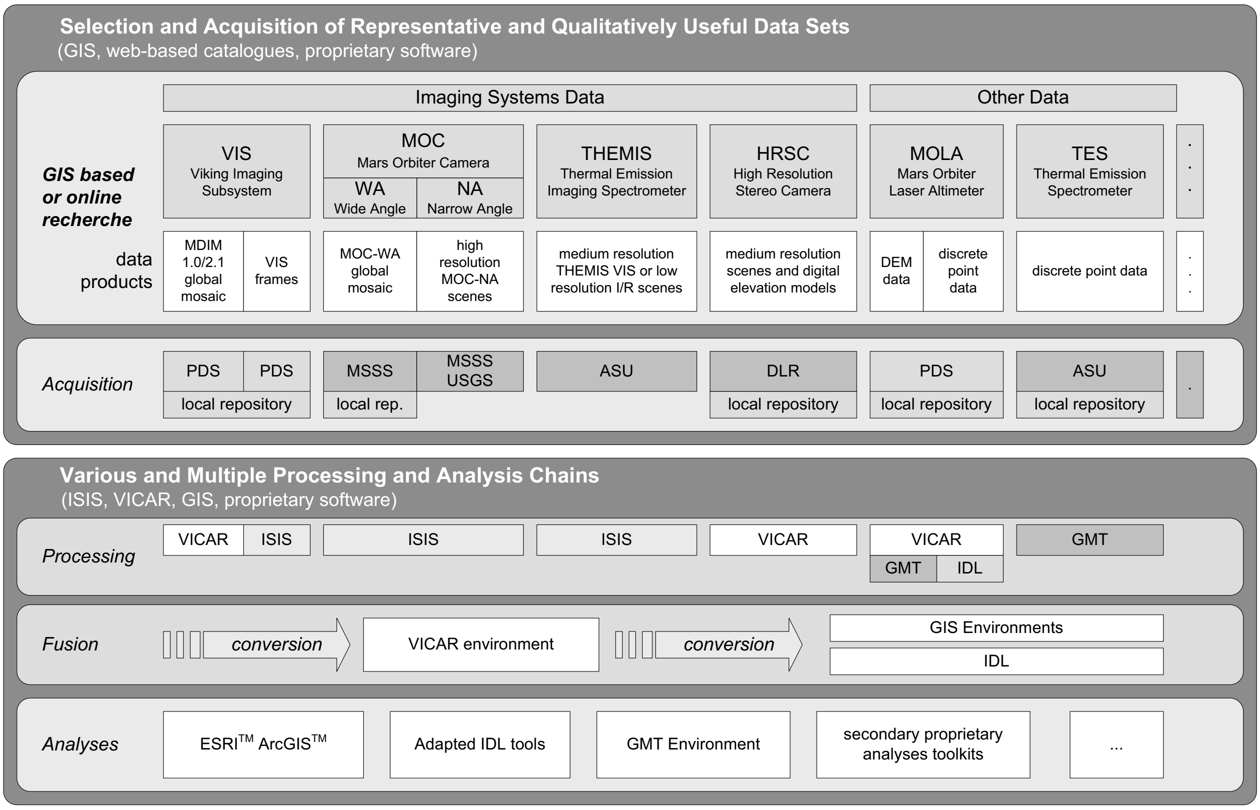

Figure 6.1.: General workflow of data search, acquisition, processing and preparation for evaluation using various sources and processing environments (compilation by author).

instrument-specific data levels.

The ISIS processing chain is used throughout this work for all data that is made available as raw data except for HRSC. Preprocessed data from web-based sources have not been used due to uncertainties regarding processing details which make exact data fusion attempts almost impossible. ISIS is currently the only system which offers out-of-the-box capabilities for processing and/or combining Viking, MOC, THEMIS and MOLA topographic data. Currently, data fusion attempts using GIS environments are more convenient to perform using ISIS-processed data due to much clearer image-label organization (see chapter 7, p. 101).

Higher-level data, such as the so-called HRSC level-4 data (see section 6.3.4) or global image mosaics, are commonly processed and combined using VICAR routines. With respect to its general concept and modularity, the VICAR system is similar to the USGS-AP/ISIS package. For obtaining a consistent reference and allowing for later combination of various data, all referenced and map projected ISIS data are transformed into VICAR image files. Combination of various datasets are also performed within this VICAR environment. Therefore, final map projected image mosaics such as the global MDIM 2.1 and MOC-WA mosaics as well as global topographic MOLA based shaded relief and terrain model maps are cropped, reprojected, and scaled in the VICAR environment.

Additional software packages which have been extensively used in this work are described in upcoming sections discussing individual data sets and analysis methods (6.3). These software tools are either based upon the commercial *Interactive Development Language (IDL)* package developed by RSI or upon

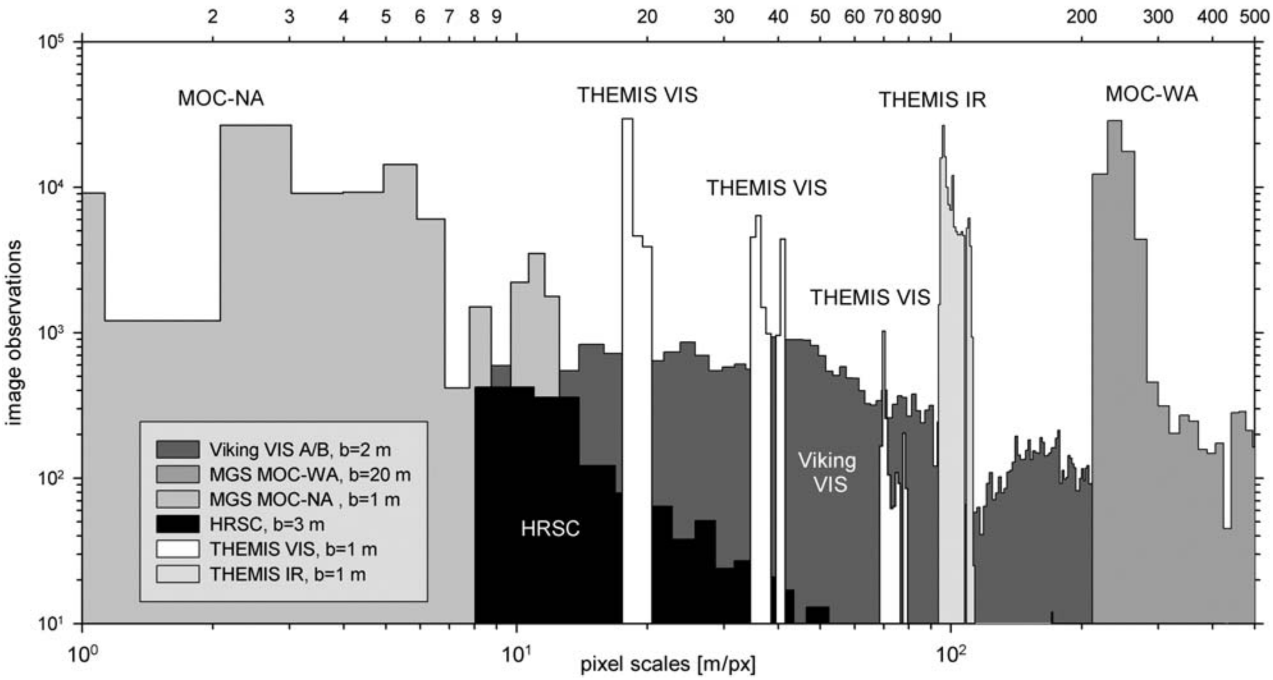

Figure 6.2.: Histograms of image resolutions obtained from remote-imaging instruments on Mars-orbiting spacecrafts versus amount of images. Histograms cover data up to a resolution of 1,500 m/px, displayed are a subset covering data up to 500 m/px. Viking VIS A/B covers 47,808 frames, binning b=2 m/px, ranging from 7-1,391 m/px, data source: USGS; MGS MOC-NA covers 85,731 images, binning b=1 m/px, displayed histogram ranges from 0.65-19.7 m/px, usable data ranges from 0.65-285 m/px (128 scenes > 20 m/px), source: MSSS; MGS MOC-WA binning of 20 m/px, MOC-WA data base consists of 67,615 scenes ranging from 114-1,000 m/px and additionally 58,653 images > 1,000 m/px, displayed in this histogram are 65,809 values with pixel scales ≤ 500 m/px, source MSSS; MO THEMIS-VIS binning of 1 m/px, 59,022 values range from 17-80 m/px, source ASU; MO THEMIS-IR covers 142,192 day- and nighttime images with a pixel scale ranging from 94-172 m/px, source ASU. HRSC covers 3354 observations binned at 3 m/px, 1,408 observations with pixel scales ranging from 9.5-364 m/px, source: data readout by author. Data compilation on the basis of image lists available in November, 2006, data are unweighted for the sake of simplicity (compilation by author)

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numerous small programs written in Perl or Python written by the author and which allow efficient data-search and download capabilities as well as automatic batch processing of large data amounts.

Such automated batch processing routines have been carried out extensively for the MOC-NA coverage of the south polar area which is covered by over 13,000 image scenes that had to be processed and mosaicked (see chapter 8, p. 109).

Software used for data fusion purposes and analysis are described in chapter 7, p. 101 about methods that have been applied.

6.3. Data Processing and Data Usage

This section focuses primarily on instrument data and data processing as well as its usage in the context of this work. Extensive descriptions of a mission's focus and details on spacecraft and in-depth instruments characteristics will not be covered as an abundance of technical documents and experiment descriptions are made available by the experiment teams.
Brief descriptions and references to documents on these topics are provided by the National Space Science Data Center (NSSDC) run by NASA/Goddard (*NSSDC*, 2006) and by work cited herein (see also Table 6.2).

Table 6.2.: Relevant imaging instruments and achievements in terms of image resolution, image size, scale and coverage. Compilation by author. A complete list including Soviet missions can be found in *Jaumann et al.* (2006).

instrument	imaging period	images	resolution [km/px]	size	coverage
Mariner 4	1965	22	>860	200×200	1%
Mariner 6/7	1969	143 (far)	>3000	704×945	
		59 (near)	≤ 0.300		20%
Mars 2/3	1971/72	60	10-100	1000×1000	
Mariner 9	1971/72	7329	50-500	932×700	2% (<0.3)
					100% (<2)
Mars 5	1973	60	≥ 0.100	1000×1000	
Viking IS	1975-1980	50488	0.150 - 0.300	1204×1056	100% (<0.4)
			(0.007 - 2,000)		
MOC-WA	since 1996	126307	0.225 - 7,500	n×3456	100%
MOC-NA		85859	0.001 - 0.012	n×2048	3%
THEMIS-VIS	since 2001	49851	≥ 0.018	n×1024	20% (<0.02)
THEMIS-IR		114319	0.098 - 0.102	n×320	95
HRSC	since 2003	1300	≥ 0.011	n×5184	50% (<0.05)

6.3.1. Viking Orbiter (VO) Data

Similar to the twin-mission approach of Mariner 8 and 9 in 1971 and 1972, the US sent two spacecraft designated as Viking Orbiters to Mars in 1975 that consisted of two orbiter and two lander units. A vidicon–based camera system onboard these spacecrafts – the *Viking Visual Imaging Subsystem (VIS)* – consisted of a high-resolution, slow-scan television framing camera mounted on the scan platform of each orbiter (VIS-A and VIS-B) with the optical axes offset by 1.38°. Each of the two cameras on each orbiter had a 475 mm focal length telescope, a 37 mm diameter vidicon and produced 1056 lines by 1182 samples raster scan images. A filter wheel between the lens and shutter held six color filter positions ranging from 0.35-0.53μm, 0.48-0.70μm, 0.35-0.47μm, 0.50-0.60μm, 0.55-0.70μm, and clear. The covered image area on the surface was roughly 40 km ×44 km from an altitude of 1500 km. For further details see e.g., *Flinn* (1977).

By the end of the mission in 1980, over 50,000 orbiter-based TV photographs of the surface with a resolution of up to 7 m/px were sent back to the Earth (figure 6.2). Figure 6.3 shows the coverage of the orbiter instruments VIS-A and VIS-B within the range of 7 m/px to 1400 km/px. 50% of all Viking photographs have a resolution better than 100 m/pxl. With the Viking missions the entire surface of the planet was imaged for the first time.

Using medium resolution data (200-400 m/px), USGS-AP built standardized global image mosaic maps and reference mosaics that have a resolution of 231 m/px and were distributed as *Mars Digital Image Mosaics (MDIM-1)*. This data set was the first to provide a complete and higher-resolution image of the Martian surface and serves as the basis for geologic and geomorphologic analyses of Mars until today. Incorrect exterior orientation data and misalignment of images caused nearly unrecoverable offsets that made combination with other (later) datasets almost impossible. In 2005, the new MDIM-2.1 was released that was orthorectified and adapted to new MOLA-based standards (e.g., *Kirk et al.*, 2000).

Besides the medium-resolution image mosaic, the Planetary Data System (PDS) provides all digital compressed images to the public. A data mirror containing all Viking image frames was maintained at DLR until the beginning of this work to allow for easy

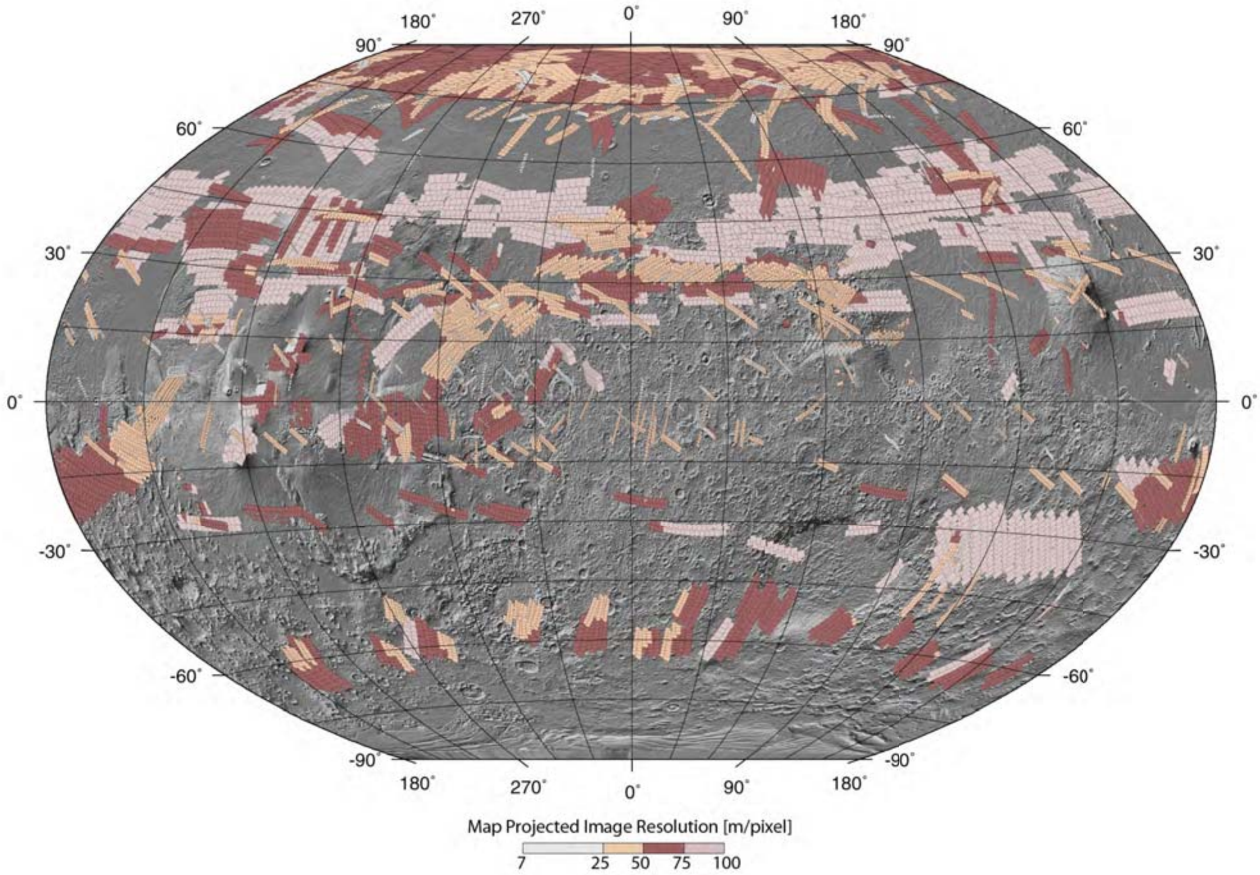

Figure 6.3.: Global distribution of Viking Vidicon VIS-A and -B frames. This representation shows the coverage of 24,907 image frames colored according to their image resolution. All images with a resolution of better than 100 m/px are shown (compilation by author, data source: USGS/PDS).

access of Viking data. Later, during work at the planetary group at FUB, the author transferred the global mosaics as well as all high-resolution image frames from the PDS server to a local storage facility to allow for a fast automatic processing and mosaicking of areas of interest.

The global Viking image mosaics MDIM-1, compiled by the USGS, have been used in the initial phase of this work as mapping base. In lack of better global data, measurements have been performed on the uncorrected version. The data is distributed with standard PDS image labels that have later been converted to VICAR image labels at DLR. At FUB the PDS files are converted for use within the

Except for file-format conversion, no data modification on the global mosaics had to be performed. After release of the corrected MDIM-2.1, global topography maps as provided by MOLA have been combined with the MDIM-2.1 and all measurements prior to MDIM-2.1 have been verified. The MDIM-2.1 was used for global studies covering lobate debris aprons and lineated and concentric crater fill features that are in the range of a few to tens of kilometers (see chapter 10, p. 155 and chapter 12, p. 183). For individual frames that cover areas of interest, the processing is still quite cumbersome and the results will fail to fit into a modern data base if the projected data is not manually adjusted, i.e., if the external orientation data is not corrected with the help of manually selected control points.

The processing chain starting from compressed raw images to final image mosaics of areas of interest is

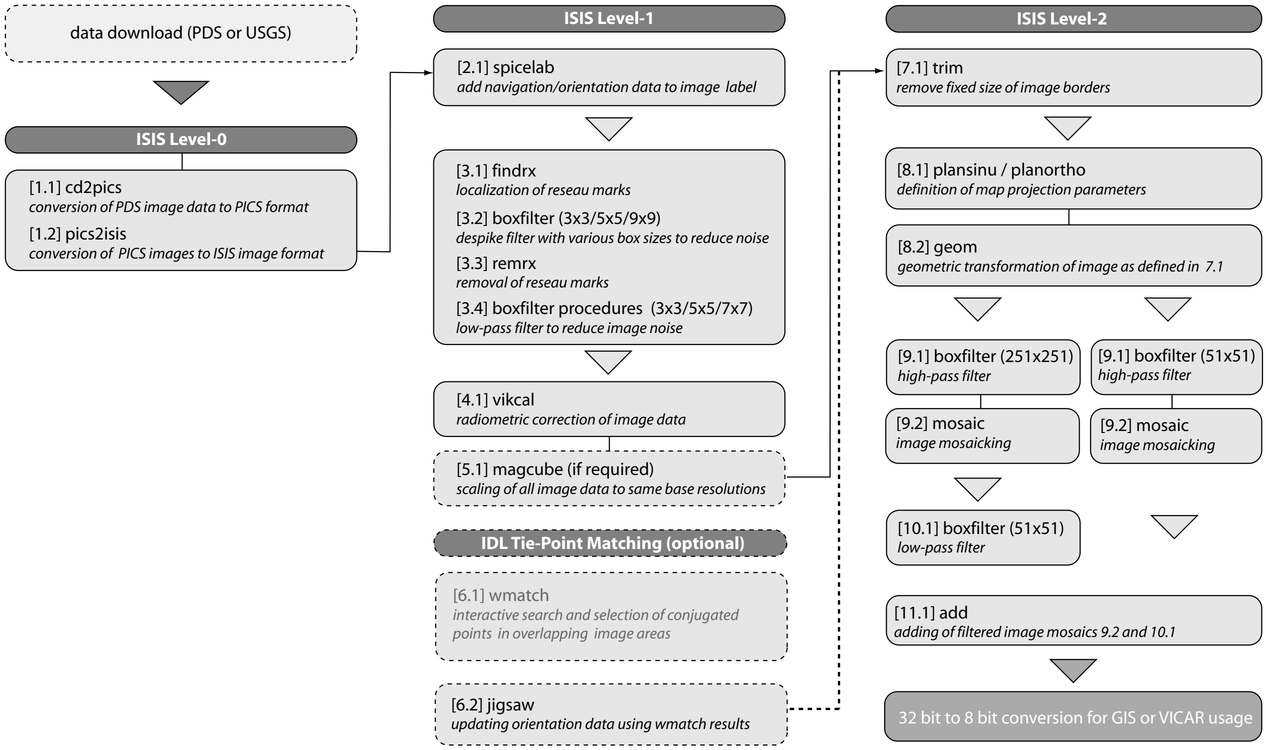

Figure 6.4.: Processing of Viking Orbiter data. Figure shows processing steps to be performed for referencing and projecting Viking frames starting with compressed level-0 data and ending with generation of seamless image mosaics (compilation by author, more details on individual parametrization are given in *van Gasselt* (2001)). The approach shown here is slightly different from procedures documented at the USGS/ISIS website. Except for the tie-point matching process procedures are implemented in a variety of scripts that were made available by the author.

well elaborated under the ISIS system. De-noising and de-speckling as well as final filtering methods are well established and lead to much better results than in the current VICAR environment although theoretically image processing capabilities are comparable and are expected to give identical results.

The processing workflow is displayed in figure 6.4 and comprises in principle decompression, combination with navigation data, reseau removal, de-speckling, radiometric calibration and filtering to obtain a level-1 image. Although image projection could theoretically be performed at that level, mosaicking of images will not lead to the expected results due to wrong exterior orientation data that first need to be updated manually. The update is performed using standard rubbersheeting methods.

After that, the projection of data (plansinu/geom procedures in figure 6.4), and high- and low-pass-filtering lead to coherent level-2 image mosaics that, however, do not fit to data of any other source. Again, manual adjustments on the mosaic have to be performed to account for that.

6.3.2. Mars Global Surveyor Instruments

After a few unsuccessful attempts to sending orbiters to Mars and its moons, Mars Global Surveyor (MGS) successfully ecountered Mars in 1996. The mission represents one of the biggest successes in Martian spacecraft exploration until today. Three instruments were on board whose data are used extensively in this work: the Mars Orbiter Camera (MOC), the Mars Orbiter Laser Altimeter (MOLA) and the Thermal Emission Spectrometer (TES).

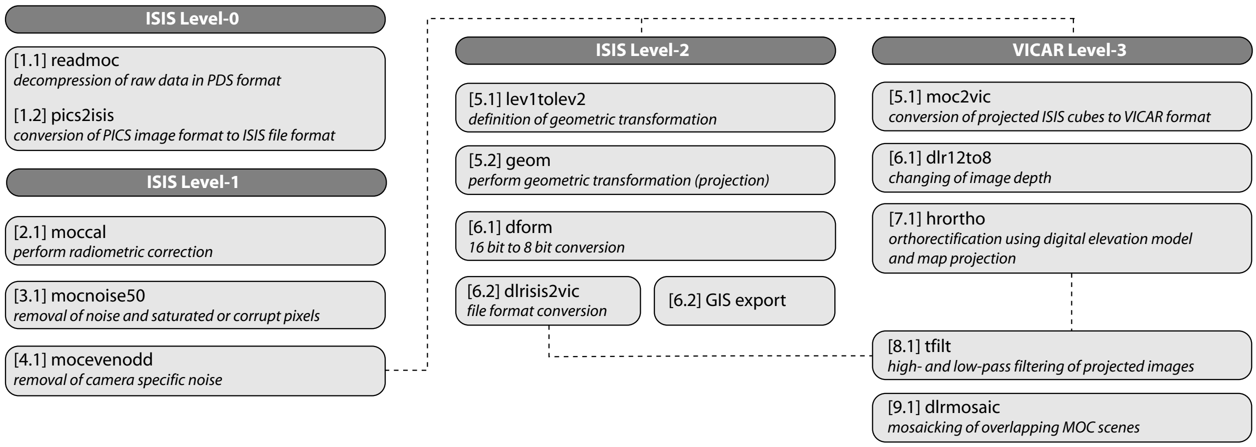

Figure 6.5.: Processing of MOC-NA and WA data using the USGS ISIS software (left) or, alternatively, using the JPL VICAR system (right) with ortho–rectification using a digital elevation model (compilation by author).

6.3.2.1. Mars Orbiter Camera (MOC) Data

The MOC instrument consists of two cameras, one being a CCD telescope known as MOC Narrow Angle Camera (NA) with a focal length of 3.5 m and a 0.4° field of view, the other one being a wide angle CCD camera (WA) with a focal length of 11.4 mm working in the range of 0.40-0.45 μm (blue) and 0.575-0.625 μm (red) and with a 140° field of view. Image resolution of the telescope reaches up to 1 m/px, but it operates mainly in the range of around 2-5 m/px (figure 6.2), while the WA camera takes images of the surface at 231 m/px.

At present, the MOC camera has obtained ~212,100 surface images of Mars as of the public release S10 in April 2006 (*MSSS*, 2006) with ~99.5% of all images being in good shape and analyzable. 85,859 images were taken with the MOC-NA telescope covering approximately 3.5% of the Martian surface (overlapping coverage not included). Image resolution of the NA–telescope ranges from 0.65 m/px to 83 m/px (mean value of 9.7 m/px) with a negligible amount of only 22 images having image resolution of worse than 20 m/px.

Over 130,000 MOC-WA images were taken at a resolution between 114.15 m/px and 19,774.94 m/px. Of these WA images, an amount of 130 scenes were used in the initial Geodesy phase to obtain a global image of Mars at a resolution of 231 m/px (256 px/degree). Malin Space Science Systems (MSSS) compiled the global image mosaic of Mars and distributed it in 2002 in a version that fits to the global IAU reference. The southern hemisphere of Mars as imaged during the MGS geodesy phase, is covered by a large dust storm; the usefulness of this image data for ground observation is therefore limited.

MOC data can be downloaded from the USGS (*USGS*, 2006b) or the Malin Space Science Systems (MSSS) website (*MSSS*, 2006). The large amount of MOC-NA scenes make a localization of images awkward using the map-based search environment at MSSS, therefore, all MOC data have been incorporated into a global planetary GIS. Data processing is primarily restricted to high resolution MOC image scenes as the global MOC-WA based image mosaic at 231 m/px does not provide significantly more information for interpretation when compared to the global MDIM 2.1. However, manual selection of high-quality MOC-WA scenes, derived from the Geodesy as well as the mapping campaign, and high- and low-pass filtering methods comparable to the established Viking VIS-A/B routines have led to a high–quality image mosaic of the western hemispheric Coprates quadrangle (MC–18) covering large parts of the Valles Marineris area (*Niedermaier*, 2001; *Niedermaier et al.*, 2002; *Wählisch et al.*, 2002).

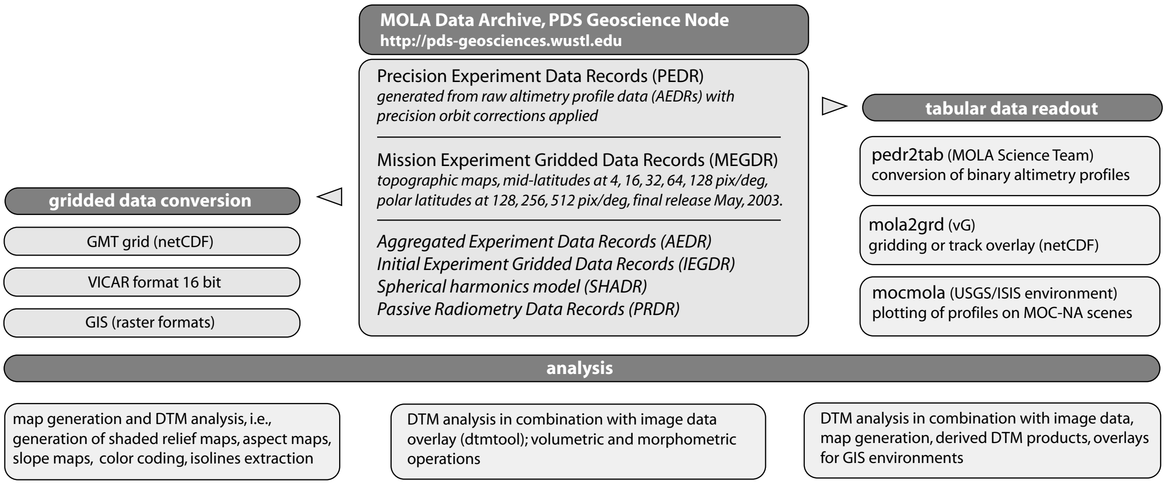

Figure 6.6.: Processing and analysis of MOLA pre-gridded and altimetry profiles data using various software environments (compilation by author).

MOC-NA data are processed using the USGS ISIS environment and covers data decompression and radiometric calibration. Map projection is accomplished by using the ISIS or VICAR environments; the latter makes use of a global MOLA-based digital elevation model for ortho–rectification that improves the overall quality of image position. For analysis based on single MOC-NA scenes, the ISIS environment is preferred for simplicity. The map-projected images provided on the MSSS website were not used in this work due to image-size differences.

6.3.2.2. Mars Orbiter Laser Altimeter (MOLA) Data

Besides the high-resolution MOC-NA telescope, the Mars Orbiter Laser Altimeter (MOLA) instrument is one of MGS's experiments that has significantly contributed to the understanding of Mars by not only providing insights into geophysical properties of Mars but also by making image interpretations in combination with detailed topographic information possible for the first time. With the release of MOLA-based point-organized data, the Viking based topographic image maps have become obsolete.

The MOLA instrument obtained about 588 million individual topographic measurements of the Martian surface between March, 1999 and June, 2001. The pulsed laser obtained altimetry measurements every 300 m along-track with a footprint coverage of about 120 m across. The absolute vertical precision is in the range of 30 m on an absolute scale and 2 m on a relative scale with a horizontal precision of about 400 m (*Smith et al.*, 2001). The polar cross-track spacing is about one kilometer due to MGS's polar orbit.

On the basis of all ground-measurements, the MOLA science team has calculated near-global digital elevation models *Mission Experiment Gridded Data Record (MEGDR)* with 128 px/degree in mid-latitudes and 256 px/degree (512 m/px) in polar regions (*Smith et al.*, 2003).

That dataset is provided as 30 quadrangle maps covering the Martian surface and have been converted from the PDS format to VICAR files for later processing and combination with image data. One representation of MOLA topography is displayed in figure 6.7.

Apart from map projected digital elevation products, areas of special interest are processed using discrete topographic point data (MOLA tracks) by using the Precision Experiment Data Records (PEDR).

In order to obtain maximum detail of areas at latitudes where MOLA gridded data records looses detail, the point measurements are extracted, gridded and map projected using Generic Mapping Toolkit (GMT) based routines. Depending on the location of the study areas, measurements are gridded us-

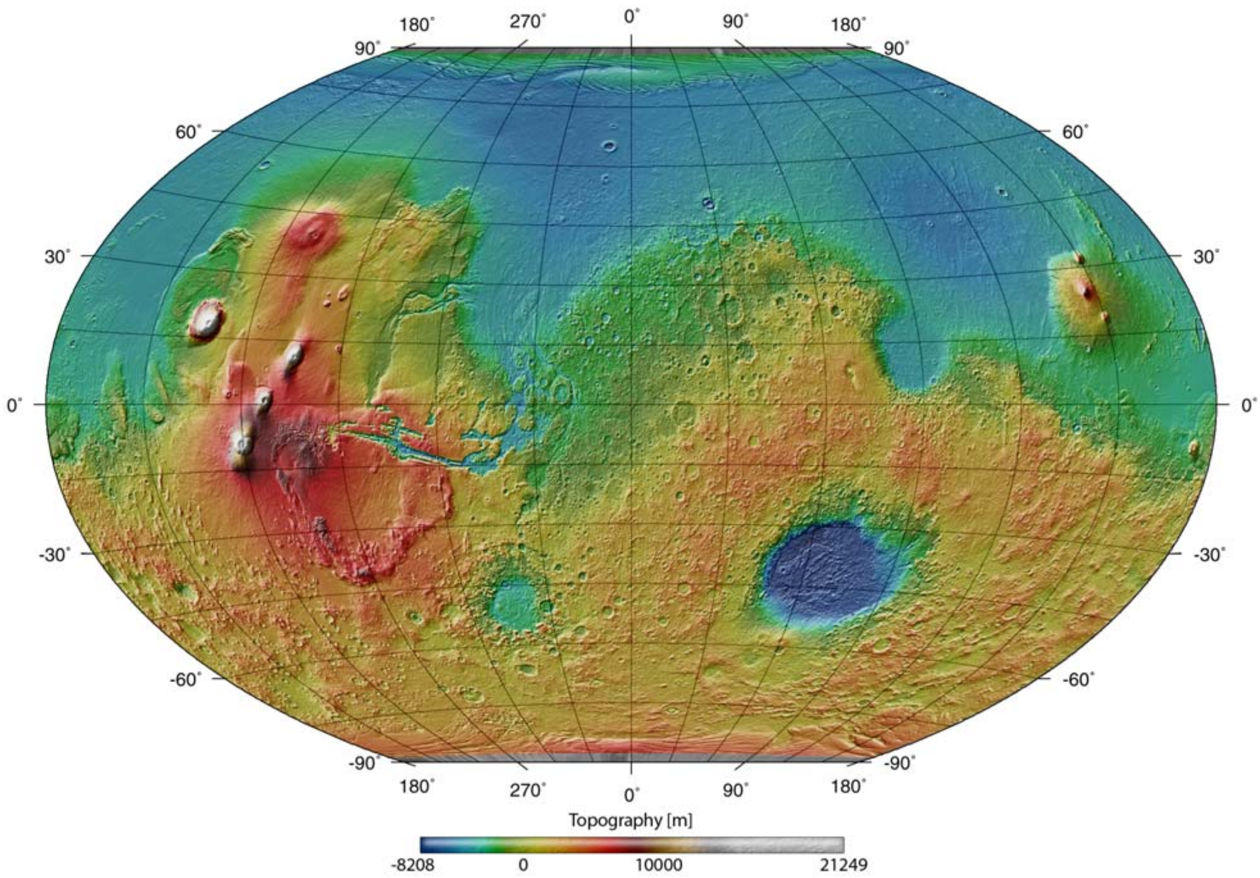

Figure 6.7.: Interpolated global MOLA topographic map as represented on the basis of 588,000,000 MOLA PEDR ground measurements (data compilation by author).

ing the best-possible spacing of data points. Consequently, such hand-crafted terrain models show normally more detail than the global MOLA mosaics.

The final terrain-model products can be imported into GIS environments or can be used in a DTM toolkit provided by DLR. Besides this, standard terrain model analyses, such as shaded relief extraction, generation of aspect- and slope maps or generation of isolines can be performed using a variety of other tools although for this work the author makes predominantly use of an adapted version of GMT (figure 6.6).

USGS developed routines, such as mocmola, to overlay MOLA altimetry profiles with MOC-NA image data up to MOC image release E10. These routines were used in cases where MOC-NA images cover an area of interest.

6.3.2.3. Thermal Emission Spectrometer (TES) Data

Data of the Thermal Emission Spectrometer (TES) onboard Mars Global Surveyor have been used far less extensively for this work when compared to MGS image and topographic data. The infrared spectrometer consists of three subsections measuring incoming infrared and visible energy using an interferometer, a radiance sensor, and a solar reflectance sensor. The interferometer covers a wavelength range from 6-50 μm. The radiance sensor measurements are in a single band ranging from 5.5-100 μm. Finally, the reflectance sensor works in the 0.3-2.7μm range (*Christensen et al.*, 1992, 2001). The spatial resolution of data is 3×3 km/px or 3×6 km/px. Individual TES tracks can be combined, gridded and color-coded to generate a spectral representation of the Martian surface.

Although quite a number of parameters are extracted

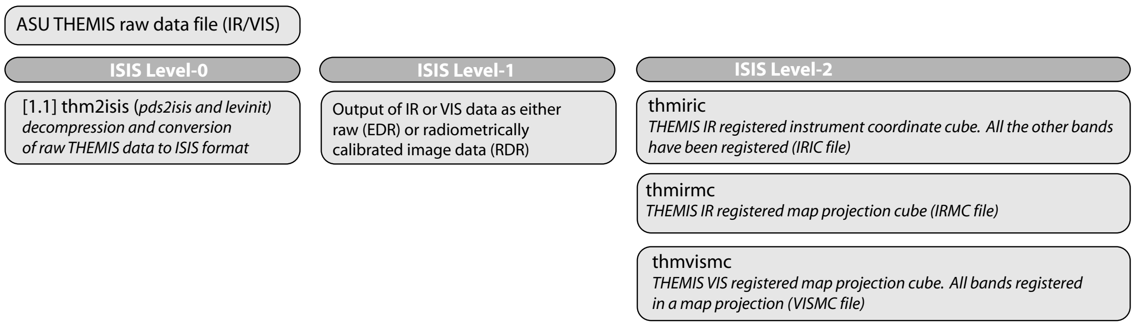

Figure 6.8.: Processing and analysis of THEMIS IR/VIS data using USGS/ISIS environment (graphic representation of USGS description (*USGS*, 2006a)).

from TES data, the author makes use of just a few: the brightness temperature, surface pressure, relative albedo, and thermal inertia. These data are completely pre-processed and modeled and are made available via PDS data servers and the TES data nodes at ASU for interpretation.

However, as with MOLA topographic profiles, all data are made available as compressed discrete and calibrated point files that have to be extracted and gridded for further interpretation requirements. Care must be taken with respect to observation angles, solar longitudes and provided "quality factors" so that only observations with an emission angle of near-90° in combination with good-quality factors and during a very confined seasonal and diurnal range are used. Otherwise the results will be smeared and cannot be interpreted correctly. Analysis using TES data are shown in chapter III.8, p. 109.

It must be kept in mind that parameters such as surface pressures are modeled assuming a constant thickness of the atmosphere of 10 km and are based upon the 1/4 degree topographic maps produced by the MOLA team. Seasonal cycles of CO_2 sublimation have been taken into account for processing and which distinguishes these products from manually processed pressure maps based on barometric height formulas. Brightness temperature data are modeled under the assumptions of black-body radiation in a wavelength range of 18-25 μm. For more detail on the derivation of values, see *Christensen et al.* (1998, 2001); *Christensen* (2006).

6.3.3. Mars Odyssey Instrument Data

In 2001, the US-mission MGS was accompanied by the US Mars Odyssey 2001 (MO). Two instruments onboard MO provide data that are used to a minor degree in this work. First there is the Thermal Emission and Imaging Spectrometer (THEMIS), second the Gamma-Ray Spectrometer and Hydrogen Detector (GRS/HEND).

6.3.3.1. Thermal Emission Imaging Spectrometer (THEMIS) Data

The THEMIS instrument consists of a thermal infrared imaging spectrometer and a high-resolution camera that are used to map the mineralogy and morphology of the Martian surface (*Christensen et al.*, 2004). The THEMIS telescope has a focal length of 200 mm and makes use of a beamsplitter to focus light onto the infrared and visible detectors. The infrared imager (THEMIS-IR) is a bolometer array and detects emitted infrared radiance in 9 bands between 6.6μm and 15.0μm centered at 6.62 μm, 7.88 μm, 8.56 μm, 9.30 μm, 10.11 μm, 11.03 μm, 11.78 μm, 12.58 μm, and 14.96 μm. The spectrum includes contributions from the atmosphere and the surface during day- and nighttime. The surface is imaged at a scale of about 100 m/px. Currently, about 97% of the Martian surface have been covered during day- and nighttime.

The visible imager (THEMIS-VIS) consists of a 1024×1024 pixel array and has a a resolution of 18 meters per pixel in 5 wavelength color bands cen-

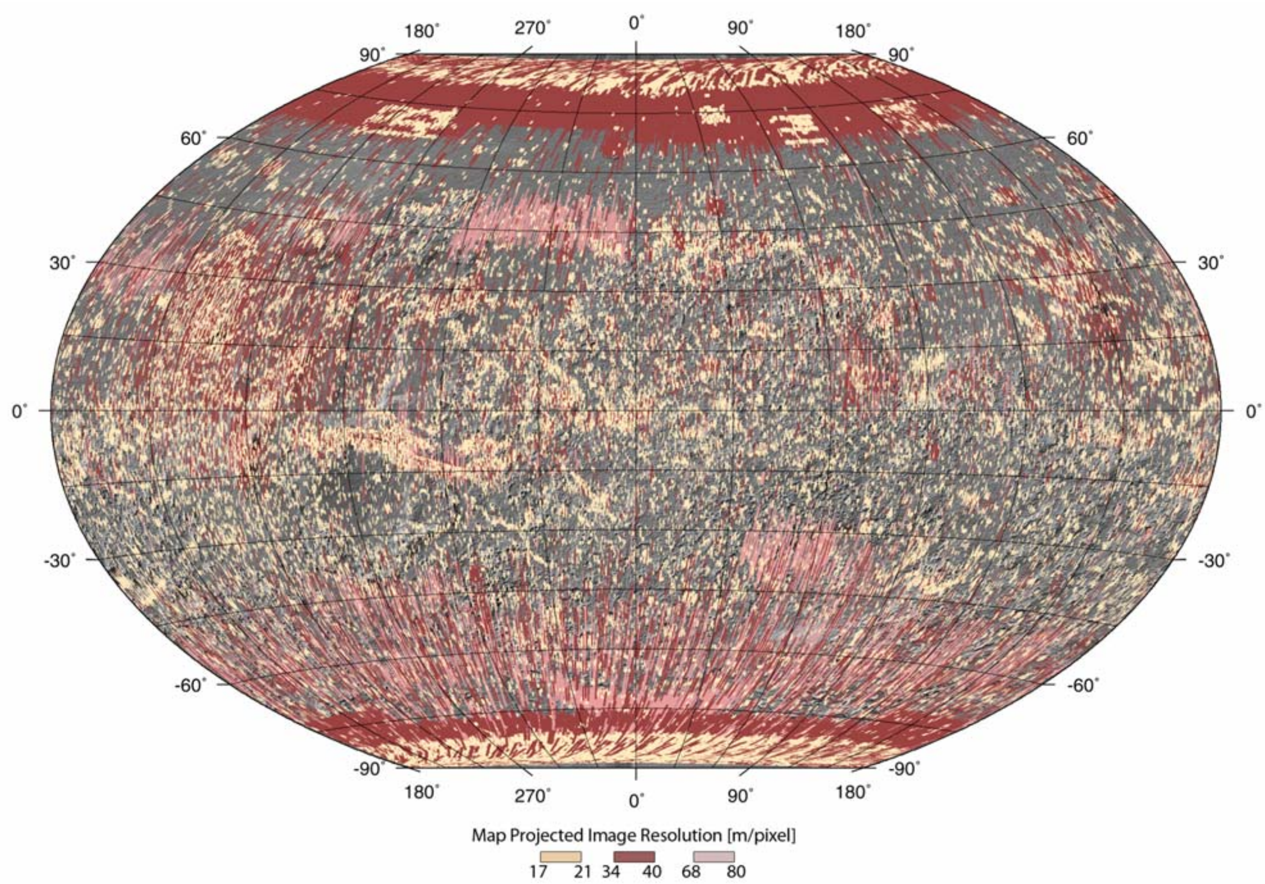

Figure 6.9.: Global THEMIS-VIS coverage. Data are colored according to pixel size, map representation includes 59,000 THEMIS-VIS scenes (compilation by author, data source: USGS).

tered at 0.423 μm, 0.553 μm, 0.652 μm, 0.751 μm, and 0.870 μm. Depending on the chosen pixel binning, returned images have resolutions of 18 m/px, 36 m/px or 72 m/px. Until July, 2006, a number of 59,000 THEMIS-VIS images and 55,300 IR day-time and 18,150 IR night-time scenes have been released to the public (figure 6.9). The THEMIS instrument is controlled and run by ASU, data are released to the public in three-month intervals via a proprietary web catalog (*THEMIS Team*, 2006b) or through the JMARS GIS implementation (*THEMIS Team*, 2006a; *Weiss-Malik et al.*, 2005; *Gorelick et al.*, 2003).

Image data processing is accomplished using USGS ISIS routines that consists of decompression and conversion to ISIS image cube format, radiometric calibration, de-striping, merging of individual THEMIS bands to a three-dimensional cube file and map–projecting the final image. Additionally to the USGS ISIS package for processing THEMIS data, ASU has made available an interactive processing web-based tool called THMPROC (*THEMIS Team*, 2006c).

THEMIS-VIS data are used in this work as it provides – similar to HRSC – a connection between low resolution Viking/MOC-WA image data and highest-resolution MOC-NA scenes. THEMIS-VIS provides insights into small with a few thousand pixels of image sizes. Due to often better radiometric properties of THEMIS-VIS, these data are used on a supplementary basis to HRSC despite its lower resolution. THEMIS–IR images have not been used extensively thus far except for the characterization of a limited area in the south polar terrain (see part III, chapter 8, figure 8.7.)

6.3.3.2. Gamma-Ray Spectrometer (GRS) Data

The Mars Odyssey Gamma-Ray Spectrometer consists of three combined instruments: the Gamma-Ray Spectrometer itself (GRS), a Neutron Spectrometer (NS) for the detection of thermal and epithermal neutrons and the High Energy Neutron Detector (HEND) for the detection of epithermal, resonance and fast neutrons. None of the data sets have been processed due to a large amount of modeling that is necessary to obtain meaningful data. Except for some pre-compiled maps, neither discrete raw data nor pre-compiled and calibrated data nor in-depth information is made available so that no processing or exact overlay with image information could be performed.

The instrument suite makes use of the fact that the Martian surface is hit by cosmic rays due to a missing magnetic field and the thin atmosphere. These cosmic rays interact with nuclei in the uppermost layer of the regolith producing secondary neutrons that again interact with subsurface matter. Depending on the kind of interaction, i.e., scattering (fast neutrons) or capture (thermal or epithermal neutrons), a so-called *neutron albedo* can be derived. The interaction of matters produce gamma-rays which are used to determine element composition of the subsurface.

The slowing-down of neutrons during collision with hydrogen atoms is used to derive information on the abundance of hydrogen at the Martian surface. Different levels of hydrogen abundances are determined through the ratio of slow to fast neutrons.

On the basis of these assumptions, global maps of hydrogen – and other elements – abundances are constructed and used for (here, limited) interpretation purposes (see *Feldman et al.*, 2004).

6.3.4. High-Resolution Stereo Camera (HRSC) Data

Mars Express (MEX) was launched in June, 2003 and started mapping in early 2004 with a highly elliptical orbit about Mars with a periapsis of 250 km and an apoapsis of 150,000 km that was later changed to 270 km and 10,000 km, respectively. Goal during the nominal mission of the High-Resolution Stereo Camera (HRSC) experiment was to map 100% of Mars's surface at a resolution better than 20 m/pixel, and 50% of the surface at a resolution better than 15 m/pixel (*Neukum et al.*, 2004). During the extended mission phase that began in 2006 and will last for one Martian year, a focus is put on high-resolution mapping of selected areas rather than to achieve a full coverage. Details on the experiment and technical results from the nominal mission phase are covered in *Jaumann et al.* (2006).

The camera has a focal length of 175 mm and operates as a line-scanner with each of the nine CCD lines (channels) consisting of 5184 pixels. The camera operates in the wavelength range of 675±90μm (nadir), 440±45μm, 530±45μm, 750±20μm and 970±45μm and has additionally two stereo and two photometry channels that are combined together with nadir to achieve 5×stereo coverage of selected areas. A Super-Resolution Channel (SRC) has a focal length of 975 mm and makes use of a 1024 x 1032 pixel CCD to provide area-exposure images. Both imagers work simultaneously around pericenter. With almost 40% of Mars's surface covered at resolutions better than 20 m/px both (figure 6.10), the HRSC and THEMIS-VIS instruments, have almost closed the gap between 231 m/px–data of MOC–WA and Viking and the high resolution MOC-NA camera operating at about <5 m/px.

Parts of this work that was started on the basis of Viking and MOC-WA imagery was later updated by higher resolution HRSC image data. Except for image re-projections, cropping and overlaying with other data (see 7), no special data processing has been performed in this work. In cases where HRSC data was used, orthorectified HRSC level–4 was preferred due to its better fit with HRSC color channels. Although these data have been studied in the context of work described in part III, no color data was used for display. Anaglyph data (epipolar images) as presented in chapter 9, p. 131 was referenced and projected using radiometrically and geometrically corrected data provided by DLR but no orthorectiffication on the basis of DTM data has been applied in order to keep original stereo geometry.

Data processing issues and high–level terrain model

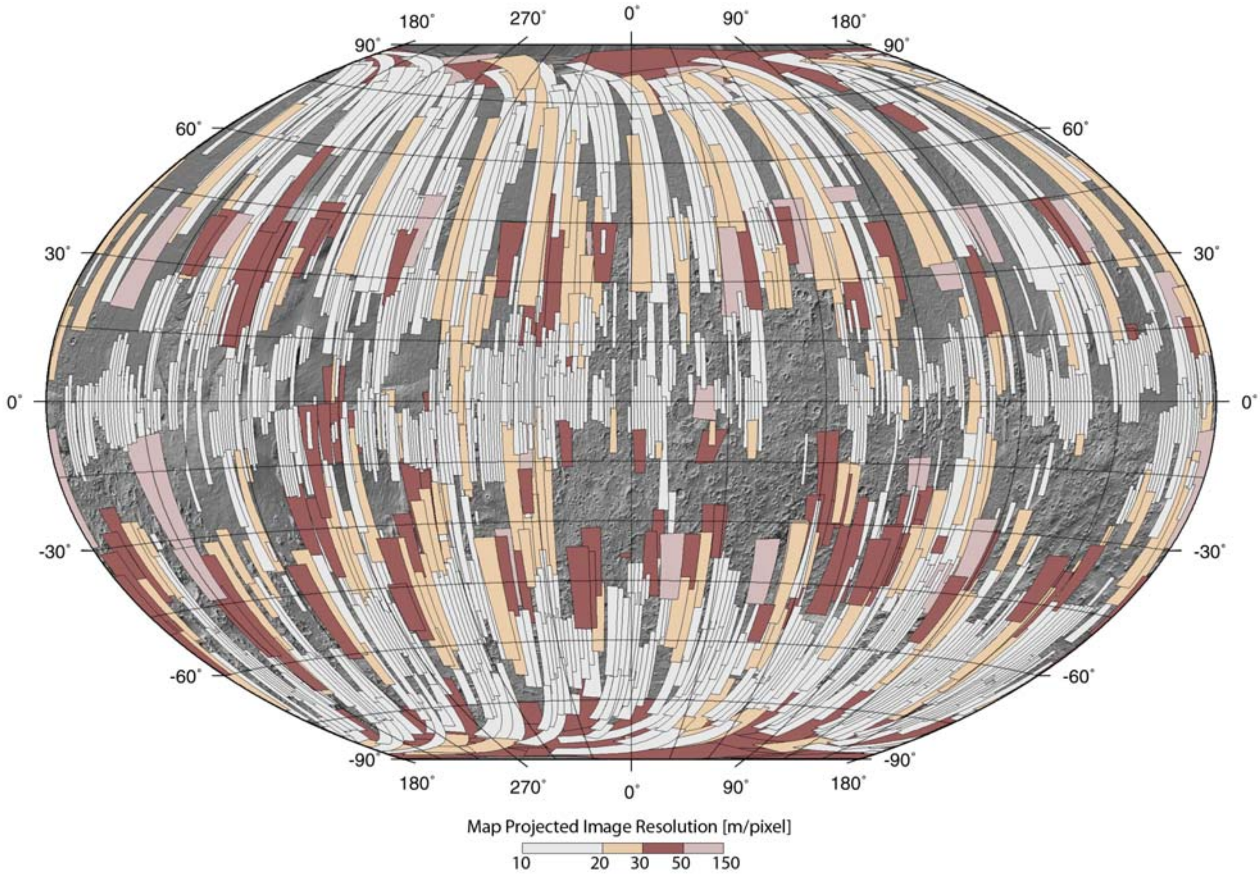

Figure 6.10.: HRSC coverage up to orbit 3354 as of August, 2006, until beginning of solar eclipse and solar conjunction phases (data read-out and compilation by author).

derivation are described and covered extensively in detail in (e.g., *Gwinner et al.*, 2005; *Scholten et al.*, 2005a,b) and is not repeated here. All data processing, is exclusively performed using VICAR routines developed and provided by DLR Berlin.

6.3.5. Landsat Enhanced Thematic Mapper (ETM)

The Thematic Mapper (TM) system is a mapping spectrometer deployed on Landsat 4 and 5 which makes use of seven spectral bands between 0.45μm to near infrared at 2.35 μm to map the Earth's surface. The Enhanced Thematic Mapper (ETM+) system onboard Landsat 7 was sent into Earth's orbit in 1999 and represents an improvement to the earlier TM version. In addition to the seven spectral bands that map at a resolution of 30 m/pixel, ETM+ makes use of a thermal band at 10.4-12.5μm and a panchromatic band covering a wavelength of 0.5-0.9μm with a mapping resolution of 15 m/px.

Most of the Earth's solid surface has been mapped with ETM+ and is used as direct analog for image interpretation when comparisons to Martian surface features observed at similar resolutions are made.

No data processing is performed for ETM data as all data are made available as geo-referenced and map-projected data for direct import into GIS environments and dataset overlays were not required. Such georeferenced image data was used for direct measurements and derivation of morphometric parameters for comparison with planetary data. □