MARS: HIGH-RESOLUTION DIGITAL TERRAIN MODEL AND ORTHO-IMAGE MOSAIC ON THE BASIS OF MEX/HRSC DATA

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Commission IV, WG IV/7

KEY WORDS: Adjustment, Orientation, Block, Bundle, DEM/DTM, Mosaic, Orthoimage, Planetary

ABSTRACT:

The High Resolution Stereo Camera (HRSC) onboard the European Space Agency's (ESA) Mars Express (MEX) has been orbiting Mars since December 2003. One of the main aims is to cover Mars globally in color and stereoscopically at high resolution. HRSC has so far covered almost half of the surface of Mars at a resolution better than 20 meters per pixel. High resolution digital terrain models (DTM) are necessary for geoscientific studies of Mars. To get a more comprehensive view of regional processes on Mars, images as well as topographic data have to be mosaicked photogrammetrically. This paper briefly describes the simultaneous adjustment of exterior orientation for six HRSC orbit strips covering the Mawrth Vallis region, based on tie point matching and bundle block adjustment as well as the derivation of a DTM mosaic with a ground resolution of 75 m per pixel and an ortho-image mosaic with a ground resolution of 12.5 m per pixel.

1. INTRODUCTION

Since December 2003, the European Space Agency's (ESA) Mars Express (MEX) orbiter has been investigating Mars. The High Resolution Stereo Camera (HRSC), one of the scientific experiments onboard MEX, is a pushbroom stereo color scanning instrument with nine line detectors, each equipped with 5176 CCD sensor elements. Five CCD lines operate with panchromatic filters and four lines with red, green, blue and infrared filters at different observation angles (Neukum et al. 2004). MEX has a highly elliptical near-polar orbit and reaches a distance of 270 km at periapsis. Ground resolution of image data predominantly varies with respect to spacecraft altitude and the chosen macro-pixel format. Usually, although not exclusively, the nadir channel provides full resolution of up to 10 m per pixel, stereo-, photometry- and color channels have generally a coarser resolution. Furthermore, image data is compressed onboard using a Discrete Cosine Transformation (DCT) algorithm. One of the goals for MEX HRSC is to cover Mars globally in color and stereoscopically at high resolution. So far, HRSC has covered almost half of the surface of Mars at a resolution better than 20 meters per pixel. Such data are utilized to derive high resolution digital terrain models (DTM), ortho-image mosaics and additional higher-level 3D data products such as 3D-views (see Fig. 12).

Standardized high-resolution single-strip digital terrain models (using improved orientation data) are derived at the German Aerospace Center (DLR) in Berlin-Adlershof (Gwinner et al. 2008). Those datasets, i.e. high-resolution digital terrain models as well as ortho-image data, are distributed as Vicar image files (http://www-mipl.jpl.nasa.gov/external/vicar.html) via the HRSCview web-interface (Michael et al. 2008), accessible at http://hrscview.fu-berlin.de. A systematic processing workflow is described in detail in Scholten et al. (2005) and Gwinner et al. (2005). For geoscience analysis and as part of a specific agency-funded contribution from the Freie Universität, multi-orbit DTMs as well as ortho-images are derived from block-adjusted exterior orientation and will also be distributed via the HRSCview web-interface as well as via the ESA Planetary Archive (PSA) interface in the near future.

Geoscientific studies can be carried out in single-orbit image data, but in order to obtain a more comprehensive view of regional processes on Mars, images as well as topographic data have to be mosaicked photogrammetrically. Until recently, the only detailed information on the global topography was provided by the Mars Orbiter Laser Altimeter (MOLA) which operated between 1997 and 2001 onboard Mars Global Surveyor (MGS) (Smith et al. 2001 and Neumann et al. 2003). MOLA-based DTMs have a ground resolution of approximately 463 m per pixel and up to 231 m per pixel at the poles. The accuracy of the DTM is 200 m in planimetry and 10 m in height.

2. INPUT DATA

In consideration of the scientific interest, the processing of the Mawrth Vallis region will be discussed in this paper. The panchromatic ortho-image and DTM mosaic (see Fig. 11) was derived from six HRSC orbits and covers an area of about 180 000 km^2 at approximately 19.6° to 28° N and 333.5° to 340.5° E. This is a relatively flat area with some large impact craters. All six HRSC orbits have good image quality (low noise and good contrast), a similar ground resolution (nadir channel) and some overlapping areas. In

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addition, several of the off-nadir panchromatic channels were acquired at full resolution (see Table 1).

	nominal ground resolution (m per pixel)		
HRSC Orbit	nadir	stereo	photometry
5325_0001	12.5	25	50
5307_0000	12.5	25	25
5289_0000	12.5	25	25
5271_0000	12.5	12.5	25
5253_0000	12.5	12.5	25
5235_0000	12.5	12.5	25

Table 1. Nominal ground resolution of the HRSC orbits (only panchromatic channels)

3. METHODS

This chapter briefly describes the basic photogrammetric processes; for more information consult the corresponding papers. For a detailed overview of HRSC image processing refers to Scholten et al. (2005).

Chapter 3.1 describes the automatic determination of tie points by software provided by the Leibniz Universität Hannover. These tie points are used as input in the bundle adjustment (see chapter 3.2), provided by the Technische Universität München and the Freie Universität Berlin, to improve the exterior orientation for single HRSC orbits and for a bundle block adjustment with more than one HRSC orbit. These refined exterior orientations allows us to adapt the HRSC derived data to the global Mars reference system defined by MOLA and will be used for the derivation of high resolution DTMs and ortho-image mosaics, described in chapter 3.3.

3.1 Determination of Tie Points

In order to process large image blocks it is necessary to enhance the concept for tie point matching presented in Schmidt et al. (2008). It is not reasonable to process the tie point matching in all images of the block simultaneously because only neighbouring strips overlap. Therefore, the block is divided into parts which consist of two neighboring strips respectively. Figure 1 shows this concept for a block consisting of three single strips.

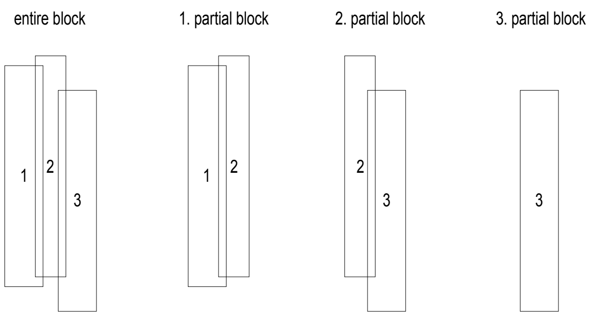

Figure 1. Concept of partial blocks

The whole block is divided into the same number of partial blocks as the number single strips where each strip once has to act as master strip. In case of the block presented in this paper six partial block have to be build and processed separately. Note that the last strip of the entire block has no partner. More information can be found in Schmidt (2008).

3.2 Bundle adjustment

The bundle adjustment approach for photogrammetric point determination with a three-line camera is a least-squares adjustment based on the well known collinearity equations. The approach estimates the parameters of the exterior orientation only at a few selected image lines, at the so-called orientation points. Because of Doppler shift measurements to estimate the position of the orbiter there are systematic effects in the observed exterior orientation. To model these effects in the bundle adjustment additional observation equations for bias (offset) and drift have to be introduced. To use the MOLA DTM as control information the least squares adjustment has to be extended with an additional observation equation for each HRSC point. These observations describe a relation between the MOLA DTM and these HRSC points. This approach is given in more detail in Ebner et al. (2004), Spiegel (2007a), Spiegel (2007b) and Schmidt et al. (2008).

The approach is valid for single orbits as well as for block configurations. But, there are differences in operational use concerning blunder detection of tie points and concerning differences between HRSC points and the MOLA DTM. The reason for these differences is that the resolution of the MOLA DTM is lower than the accuracy of HRSC points and depends on terrain slopes. That circumstance can occur, for example, at the rims of craters. Another reason for differences is that the MOLA data does not contain small craters in contrast to the HRSC data.

The blunder search for single orbits is carried out in two steps. First, blunders of tie points are detected without using the MOLA DTM, i.e. only ray intersections are used for this investigation. In the second step, the DTM is introduced and the HRSC points are registered to the MOLA DTM. During this step HRSC points are eliminated that do not fit to the MOLA DTM surface. After the two steps, we have an exterior orientation for the orbits and a data set of tie points without blunders and without big differences between MOLA DTM and HRSC points.

To compute blocks it is necessary to divide the blocks temporary into single orbits. With the divided orbits a blunder search for single orbits can be arranged (two steps). The resulting set of tie points without blunders is used instead of the original tie point set for the next steps. In the third step, ray intersections of tie point located in the overlapping area of two orbits are investigated. The reason for this is to detect blunders in HRSC points, that are built from tie points located in two or more orbits. The fourth step is to register the remaining HRSC points to the MOLA DTM and compute the block adjusted exterior orientations.

3.3 DTM derivation

Derivation of DTMs and ortho-image mosaics are basically performed using software developed at the German Aerospace Center (DLR), Berlin and is using the Vicar environment developed at JPL. For our DTM derivation, the main processing tasks are first a pre-rectification of image data using the global MOLA-based DTM, then a least-squares area-based matching between nadir and the other channels (stereo and photometry) in a pyramidal approach and finally, DTM raster generation.

Parameters for the derivation of preliminary DTMs are individually adapted to the image quality and to the initial DTM. The result is a preliminary HRSC-based DTM which is used for further refinements in subsequent processing iterations.

In general, for DTM derivations all five panchromatic channels are used, because this has been shown to produce better results over only using the nadir and stereo channels (see Heipke et al. 2007), therefore the matching scale for the least-squares area-based matching was set to the photometry channel resolution.

Iterative low pass image filtering (Gauss and mean filtering) is applied in order to improve the image matching process by increasing the amount and quality of object points and in order to reduce possible misdetections caused by image-compression artefacts and noise. Depending on the results (object point distribution and the intersection of the object points) after each iteration, selective sub-areas are newly filtered.

For all our calculations we have only used objects points defined by at least triple intersections. In order to eliminate blunders a threshold value (depending on the intersection of the object points) for the intersection accuracy is set.

The DTM grid size depends on the object point distribution, point accuracy, matching resolution and exterior orientation accuracy. For the investigated area two DTMs were generated: first, a DTM-raster by interpolation and filtering of multiple object points, and secondly, a DTM-raster without interpolation and filtering. If more than one object point is in the raster-grid, the mean value is calculated. In the next step, all gaps in the DTM without interpolation are filled with values from the interpolated DTM. After this, box filtering is employed to reduce possible artefacts and blunder.

As an additional DTM quality control we calculated elevation differences to the MOLA DTM (see Fig. 3, Fig. 5 and Fig. 7) and generated shaded relief DTMs for a visual control (Fig. 8, Fig. 9 and Fig. 10)

4. RESULTS

In this chapter, the results of the bundle adjustment and the DTM derivation will be discussed for three cases. Fig. 2, Fig. 4 and Fig. 6 shows the mean displacement in planimetry of object points between neighbouring strips using nominal exterior orientation, adjustment as a single strip and adjustment as a block. Annotation: The arrow scale in Fig. 2 is 200 m and in Fig. 4 and Fig. 6 50 m.

4.1 Nominal exterior orientation

The mean displacement in planimetry for all six orbit strips is 269 m. Two overlapping areas show high differences in planimetry (see Fig. 2): Compared with previous results of other orbits; the difference in planimetry of the other three overlapping areas is small. The mean height difference between HRSC object points and the MOLA DTM is 23 m, but they are irregularly distributed over the whole area (see Fig. 3).

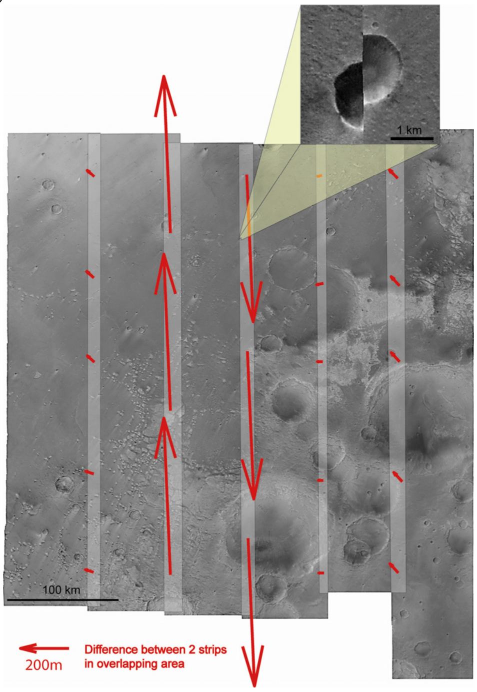

Figure 2. Results before adjustment (planimetry)

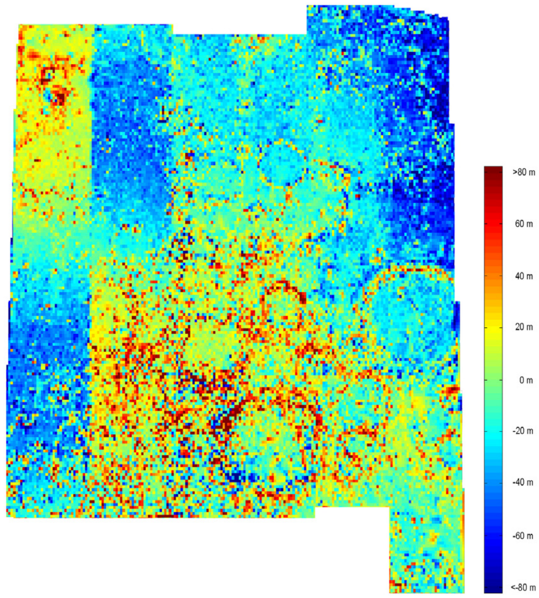

Figure 3. Results before adjustment (height diff.)

4.2 Adjustment as single strip

The mean displacement in planimetry for all six orbit strips is 39 m (see Fig. 4). The height differences in the two overlapping areas are smaller compared with the nominal exterior orientation. Furthermore, the mean height difference between the HRSC object points and the MOLA DTM is 5 m and thus smaller too (see Fig. 5). In principle, there are no systematic variations between the HRSC DTM and the MOLA DTM. The reason for the differences are on the one hand, that the resolution of the MOLA DTM lower is than the accuracy of the HRSC points and on the other hand that the higher-resolution HRSC-based DTM, as well as the lower-resolution MOLA DTM, includes areas without any object point information. In these areas elevation differences are relatively large.

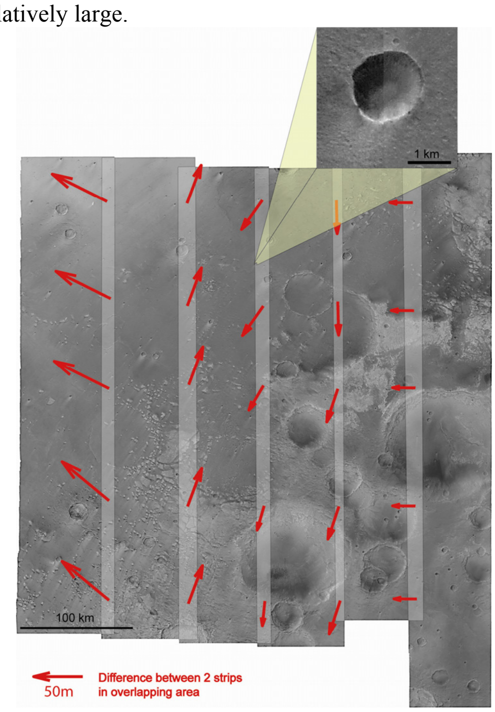

Figure 4. Results of single strip adjustment (planimetry)

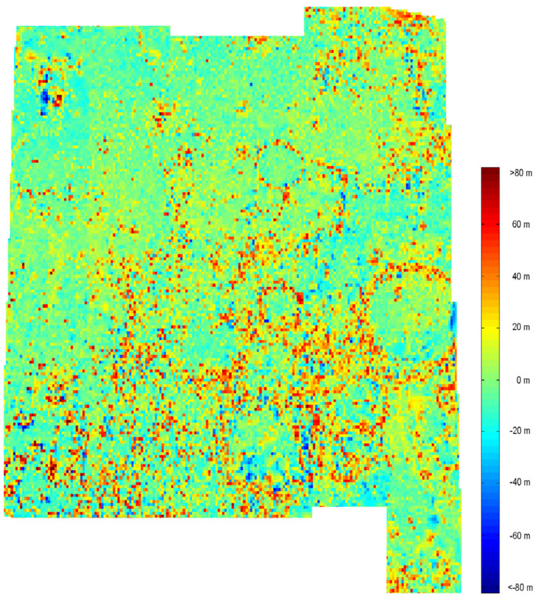

Figure 5. Results of single strip adjustment (height diff.)

4.3 Adjustment as a block

The best results are achieved by bundle block adjustment. The mean displacement in planimetry for all six orbits is 6 m (see Fig. 6). The mean height difference between the HRSC object points and the MOLA DTM is 4 m (see Fig. 7). The improvement of the height difference between the HRSC object points and the MOLA DTM is very small because the HRSC data has been adapted to the MOLA DTM very well already in the single strip adjustment (see case 4.2).

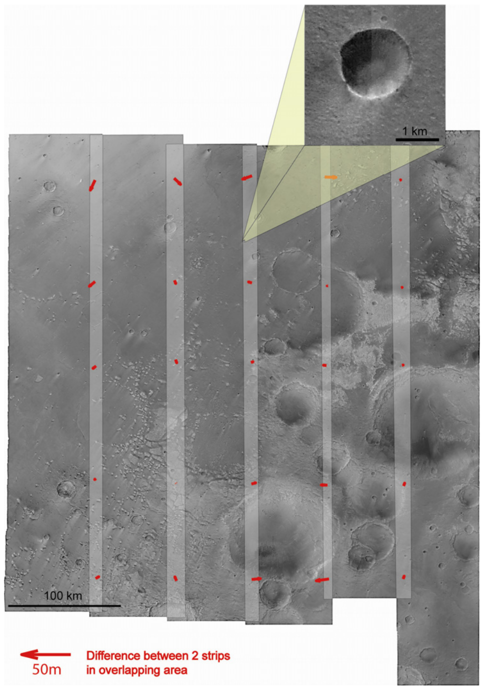

Figure 6. Results of bundle block adjustment (planimetry)

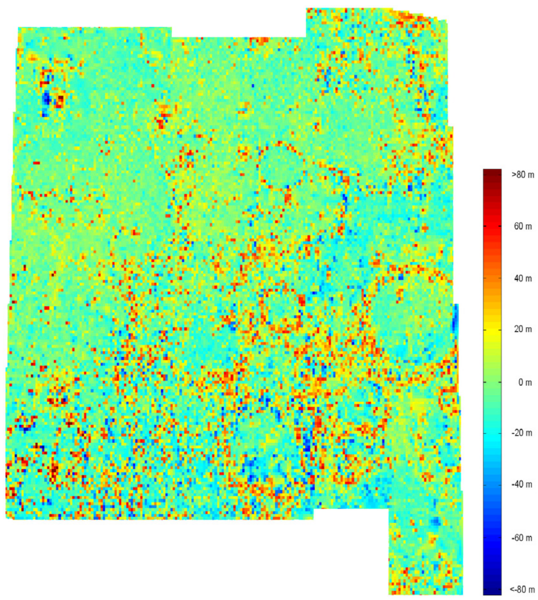

Figure 7. Results of bundle block adjustment (height diff.)

The results of bundle block adjustment are used for the derivation of a high resolution DTM with a ground resolution of 75 m per pixel and a panchromatic ortho-image mosaic with a ground resolution of 12.5 m per pixel.

Image filtering approaches are advantageous for nearly all HRSC orbit strips. However, problems usually occur in featureless areas. The area-based matching shows a higher correlation in textured image parts and a lower image correlation in less-textured image parts. Compared to the non-filtered data, the image filtering results in an increase of the generated object points of on average about 29%.

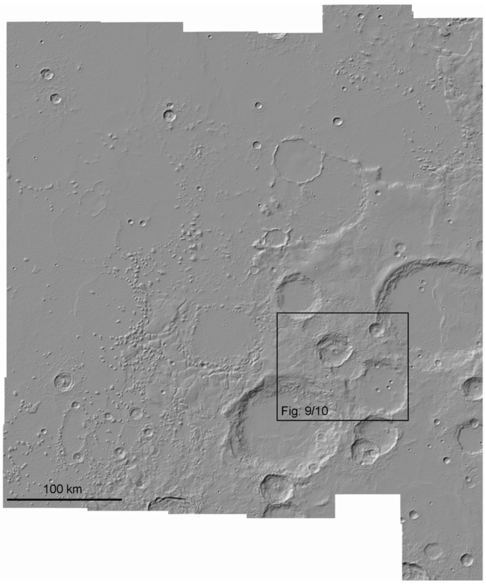

Figure 8. Shaded relief HRSC DTM mosaic

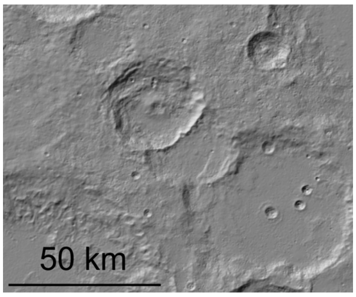

Figure 9. Detail HRSC DTM

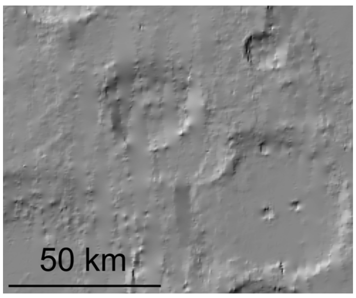

Figure 10. Detail MOLA DTM

The mean percentage of 5-ray points for all six orbit strips is 78.5%.

The mean intersection accuracy of all object points used for the DTM mosaic is 0.6 multiplied by the nominal nadir resolution. This is equivalent to approximately 7.5 m.

The quality of the derived DTM is well-reflected in the shaded relief (see Fig. 8, Fig. 9 and Fig. 10). Of course, compared to the MOLA DTM the higher resolution HRSC DTM mosaic includes more detail and is altogether more complete.

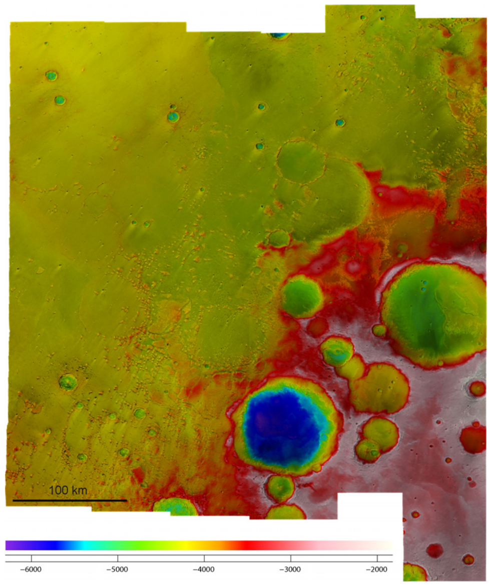

Figure 11. Ortho mosaic with superimposed color-coded elevation

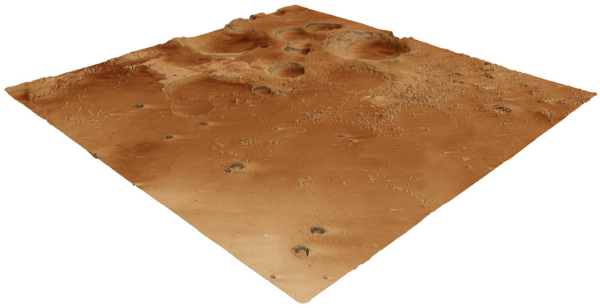
Figure 12. 3D-View (part of DTM with false color)

5. CONCLUSIONS AND OUTLOOK

The exterior orientation parameters can be improved for a single orbit and for image blocks using the bundle adjustment. The exterior orientation data that were adjusted in a strip can be used for ortho-image mosaics and DTMs, and provides good results apart from the elevation difference to the MOLA DTM. The results of bundle block adjustment provided the best accuracy and adapt the HRSC-derived data to the global Mars-reference system very well. So far, four further DTM mosaics of between two and eleven orbits have been adjusted using bundle adjustment with good results. Further studies shall show that a block adjustment with more orbit strips is possible.

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7. ACKNOWLEDGEMENT

We thank the HRSC Experiment Teams at the German Aerospace Center (DLR), Institute of Planetary Research Berlin as well as the Mars Express Project Teams at ESTEC and ESOC for their successful planning and acquisition of data. We gratefully acknowledge funding of this work by the German Space Agency (DLR) Bonn through grants no. 50 QM 0104 and 50 QM 0301.