ON THE DETECTION AND EXPLOITATION OF LAYOVER IN MAGELLAN SAR IMAGERY

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ABSTRACT

In this paper we present a concept for the refinement of Digital Elevation Models (DEMs) derived from Magellan SAR images of planet Venus. We deal with the automated extraction of height information in foreshortening and layover areas, as well as the associated recognition of layover. A stereo matching algorithm specially suited to the geometric properties of foreshortening and layover regions was developed and implemented. First tests carried out on simulated layover maps indicate that the match points obtained can be utilized for estimating terrain height in SAR layover areas.

KURZFASSUNG

In der vorliegenden Arbeit wird ein Konzept zur Verfeinerung von Digitalen Höhenmodellen, welche aus SAR-Bildern des Magellan-Projekts erstellt wurden, vorgestellt. Wir befassen uns mit der automatischen Extraktion von Höheninformation in Foreshortening- und Layovergebieten, sowie der damit verbundenen Erkennung von Layover. Ein speziell auf die geometrischen Eigenheiten von Foreshortening- und Layovergebieten zugeschnittener Matchingalgorithmus wurde entwickelt und implementiert. Erste Versuche, welche auf simulierten Layover Maps ausgeführt wurden, deuten auf eine Verwendbarkeit der Matchpunkte zur Geländerekonstruktion in Layovergebieten hin.

1 INTRODUCTION

During NASA's Magellan Mission (1989 - 1994) to planet Venus, more than 95 % of the planet's surface was imaged by the onboard radar sensor, resulting in over 400 Gbytes of SAR imaging data. One of the major goals of the mission was the computation of a high-resolution map of the whole planet, a tool which plays a crucial part in the geophysical analysis of all planetary processes [Ford, 1992]. Therefore, special attention needs to be paid to the development of techniques for extracting height information from SAR imagery which are suited to this particular data set.

Magellan SAR images were acquired in three cycles, denoted as Cycles I, II and III. In Cycles I and III the radar was looking to the left, whereas in Cycle II the imaging configuration was right-looking. This means that for many areas on Venus a same-side stereo pair as well as a corresponding opposite-side image are available. Information from same-side stereo images can be extracted by using conventional stereo matching techniques, which were originally designed for optical data. Contrarily, SAR images illuminated from opposite sides exhibit a high degree of geometric and radiometric dissimilarities, which obstruct the joint use of such imagery for the automated reconstruction of topography.

Radar layover is a special problem that arises when dealing with SAR imagery of mountainous terrain, with slopes steeper than the off-nadir look angle of the SAR sensor. For these slopes, the top of the mountain is closer to the sensor than the bottom. Since radar is a range measuring device, this configuration leads to particular geometric distortions, which are denoted as layover. Due to the superposition of multiple scatterers from different parts of the terrain, layover areas appear in the SAR image as bright regions with the original geometric order being reversed. A more detailed discussion of the SAR imaging geometry, including the layover phenomenon, can be found in, e.g., [Leberl, 1990] or [Schreier, 1993]. Fig.1 illustrates how a decrease in sensor look angle leads to a successive compression of the foreshortening areas, and finally to layover. Note the reversed positions of A' and B' in the ground range projection, when compared to the true positions A and B in the terrain. Further decrease in sensor look angle would cause a growing of the layover region. According to [Kropatsch, 1990], one can distinguish between so-called active and passive layover areas. Active areas are those which produce layover, because the local terrain slope exceeds the sensor look angle. Passive layover areas are only affected by layover because of an adjacent active layover. (In Fig.1, the passive regions are part of the flat areas at the bottom and top of the slope.)

In Magellan SAR data a considerable amount of layover can be found, due to the steep look angle used in Cycles II and III (between 11 deg and 25 deg). Examples of layover in Magellan images are given in Figs.2 and 3. The layover area shown in Fig.2 is located on Venus at about 8 deg S, 74 deg E. The layover was recognized by stereoscopy, since due to geometric and radiometric perturbations layover areas do not fuse properly in stereoscopic vision. Fig.3 shows a 26 km x 43 km section of the Venusian surface at 29.5 deg S, 142.5 deg E. The technique used to identify the layover regions in (a) and (b) was developed by [Connors, 1994], and will be briefly described in the next section.

When automated matching methods are applied to stereo images, the geometric and radiometric differences associated with layover result in inaccurate or missing match points, which lead to errors in the derived Digital Elevation Model (DEM). Similar problems arise when employing shape-from-shading techniques, which use the pixel gray values to cal-

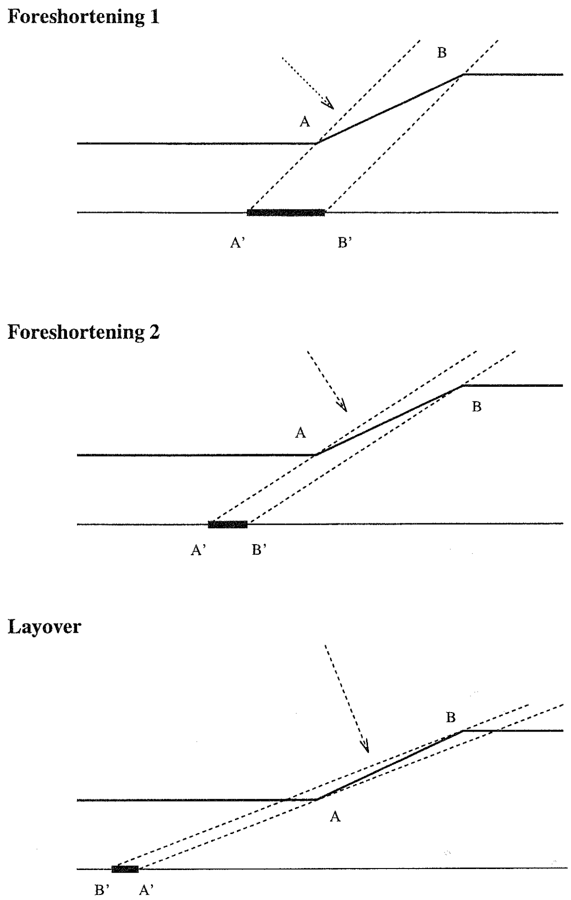
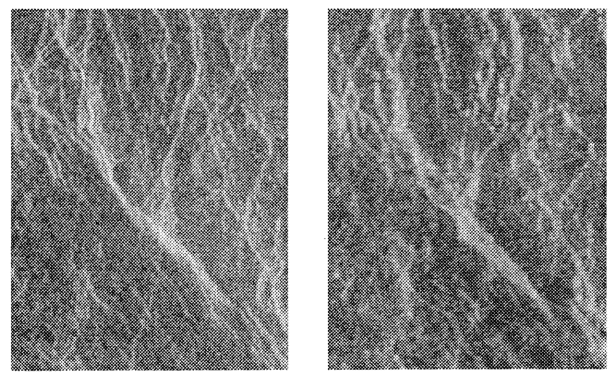
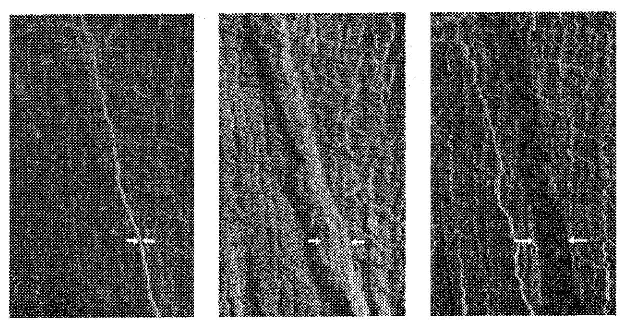


Figure 1: *Illustration of foreshortening and layover. A decrease in sensor look angle (from top to bottom) leads to successively narrower foreshortening areas, and finally to layover.*



(a) (b)

Figure 2: *A stereo image pair from the Magellan data set, captured with a look angle of 40 deg (a) and 21 deg (b). Image size is approximately 17 km x 22 km. The apparent changes in the central part of the image were classified as layover by stereoscopy.*



(a) (b) (c)

Figure 3: *Three views of an area on Venus' surface, acquired from the left with a look angle of 34 deg (a) and 17.5 deg (b) during Cycles I and III, respectively, and from the right at 25 deg (c) during Cycle II. The region marked by an arrow was classified as layover in (a) and (b) by [Connors, 1994].*

culate the slopes of the viewed terrain. The application of a multiple image SAR shape-from-shading algorithm to Magellan data is reported by [Leberl, 1991]. However, if layover areas are not recognized as such, the bright layover pixels caused by superposition of multiple scatterers are misinterpreted as produced by terrain slopes alone. Therefore, we believe that the recognition and proper treatment of layover can be used for a refinement of both stereo and shape-from shading derived DEMs. An improvement of the DEM in layover areas can be of special interest in planetary sciences, since steep slopes which lead to layover are often particularly interesting features for geological and geophysical interpretations.

In the following we present a concept for the automated detection and exploitation of layover in Magellan SAR imagery, and describe the first steps of its implementation. In particular, we address the use of simulation for the generation of test data, and the development of a matching algorithm specially suited to SAR foreshortening and layover regions. First tests on simulated imagery indicate that our matching method can be utilized for a refinement of stereo-derived DEMs in layover areas.

2 CONCEPT AND PREVIOUS WORK

Our approach is motivated by a study on the extraction of height information from Magellan data carried out by [Connors, 1994]. In that work, discretely dipping surfaces related to faulting were investigated in the context of geophysical applications. The features of interest appear in the SAR image as bands of increased brightness, which are either foreshortening or layover areas. The proposed algorithm reconstructs terrain slopes, and at the same time distinguishes between foreshortening and layover. Its basic idea can be outlined as follows (see Fig.3): First, corresponding areas are identified in the Cycle I/III same-side stereo pair. Then, the across-track widths of the two areas of interest are used along with knowledge about the corresponding sensor look angle to calculate two possible solutions for the terrain slope. These two solutions reflect an ambiguity between foreshortening and layover which arises for one of the stereo images. In order to resolve this ambiguity, the opposite-side image acquired during Cycle II needs to be taken into account. Once the corresponding feature is identified in the opposite-side image, its across-track width serves to decide which of the two candidate solutions is the correct one, thus resolving the remaining foreshortening/layover ambiguity. The image processing tasks involved in the procedure (i.e., the identification of the areas of interest and the establishment of correspondences between them) were done manually.

The purpose of the project described in this study is twofold. On the one hand the goal is to automate the image processing tasks described above, so that the whole process of height estimation requires no, or at least very little, human interaction. On the other hand, we intend to extend the ideas originally developed for the special case of discretely dipping surfaces to the more general problem of improving the accuracy of stereo-derived DEMs in foreshortening and layover areas. As already mentioned before, the different geometric appearance of both foreshortening and layover regions in the two partners of a stereo image pair poses special problems when applying conventional stereo matching algorithms, normally based on gray value correlation. Therefore, a matching algorithm which is able to cope with foreshortening and layover needs to be robust to the variations in across-track width produced by the change in ground range resolution associated with foreshortening and layover. Furthermore, in those cases where the same feature is foreshortened in one stereo image, but laid over in the other one, an appropriate reversal of match points needs to be carried out, in order to obtain correct height estimates. Possible interactions between different layover regions can lead to even more complex situations: Two layover regions which appear as separate features in one SAR image may have merged into one single layover region in another image of the same scene, acquired with a steeper look angle. A thorough discussion of possible scenarios arising from fusion between different layover areas is given by [Kropatsch, 1990]. At the current status of our project, interactions between different layover areas are taken into account by a simplified model which assumes that layover regions which are separate in one image, but joint in the corresponding stereo image, are just at the initial stage of merging, where relationships between adjacent pixels are still preserved. The validity of this assumption is currently being tested on simulated imagery, and, if necessary, the model will be refined.

3 IMPLEMENTATION AND RESULTS

The realization of the concept discussed above can be divided into several steps, two of which are presented and illustrated in the following. First, a simulation program was implemented in order to provide a test environment for the newly developed algorithms. The second issue we address is the development of an image matching algorithm specially designed for SAR foreshortening and layover areas.

3.1 Simulation

In our project, the need for simulation arises for several different reasons. First of all, simulation is an important tool for verification when dealing with planetary data, due to the lack of ground truth. Secondly, simulation provides inexpensive and flexible test data for the development of new image processing algorithms, which often cannot be obtained from other sources. A third particular need for simulation comes up when trying to combine SAR images taken from opposite sides: Due to the strong geometric and radiometric differences caused by opposed illumination directions, the identification of corresponding features in such kind of imagery requires knowledge about the radar imaging geometry. When automating the identification process, this knowledge can be incorporated by using simulation. Finally, we also employ sequences of simulated images acquired with varying sensor look angle in order to get a better understanding of how the layover manifests itself in the image, and to observe the effects of interactions between different layover regions. An example of such a simulation series can be seen from Fig.4. Input to the simulator was a DEM of the Ötztal, a rugged terrain in the Austrian Alps, where layover occurs frequently.

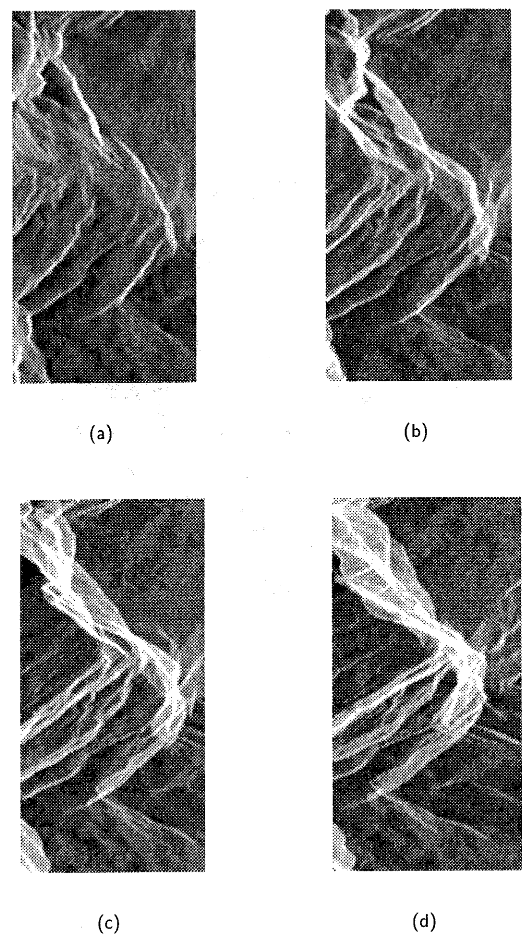
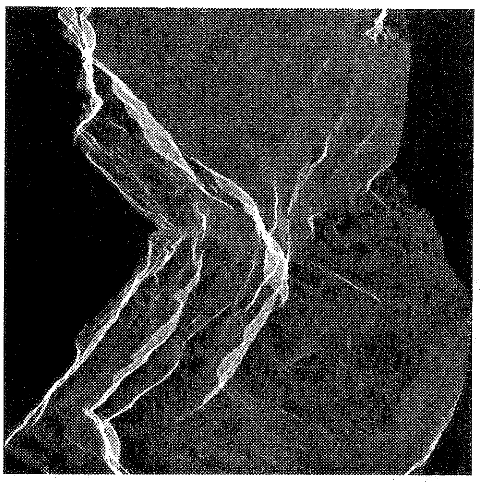
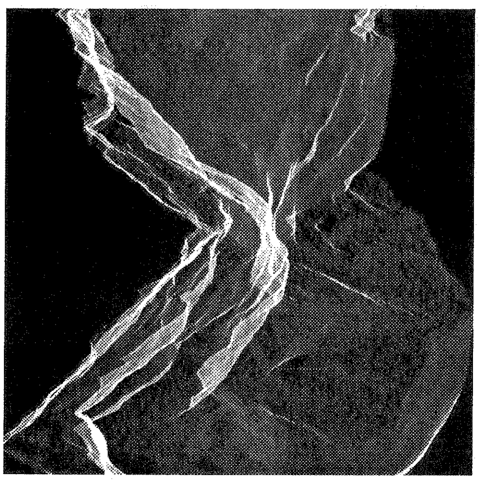


Figure 4: *The simulated views (a) - (d) correspond to look angles of 40 deg, 26 deg, 20 deg, and 15 deg, respectively. They demonstrate the transition from extreme foreshortening in (a) to beginning layover in (b), and the growing and overlapping of the layover regions in (c) and (d).*

The implemented SAR simulation program is based on a cosine reflectance model and the assumption of a straight sensor flight path. In addition to the simulated SAR image, a so-called layover map is generated, which marks those parts of the image affected by layover. Fig.5 shows again a SAR stereo image pair generated by simulation, with the corresponding layover maps given in Fig.6. These layover maps were employed as test data for the matching algorithm presented in the following section.

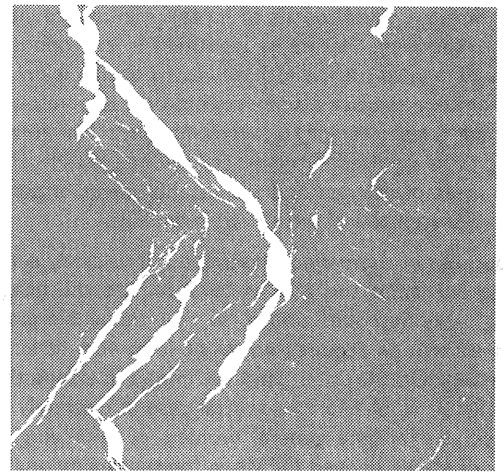


(a)

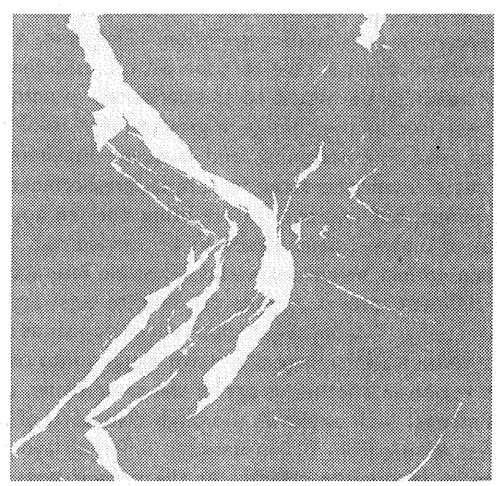


(b)

Figure 5: *Simulated SAR stereo image pair, with an off-nadir look angle of 26 deg (a) and 20 deg (b).*



(a)



(b)

Figure 6: *Layover maps corresponding to Fig.5. Layover areas are displayed in white.*

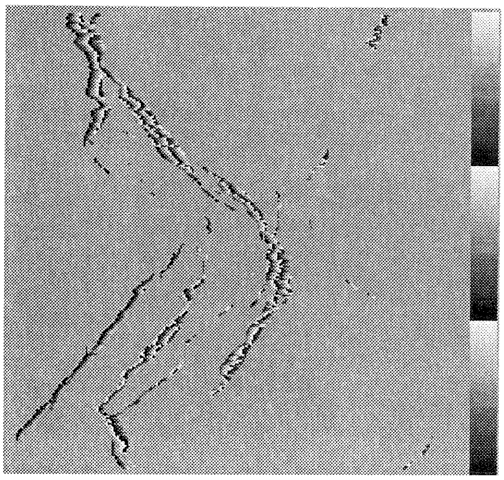
3.2 Matching

The aim was to develop a stereo matching algorithm which is able to cope with the variations in across-track width associated with foreshortening and layover. In other words, the determination of corresponding widths, a task which was performed manually by [Connors, 1994], should be automated. Further design goals were to achieve robustness to speckle noise, and the proper treatment of those situations where originally separate layover regions start to merge.

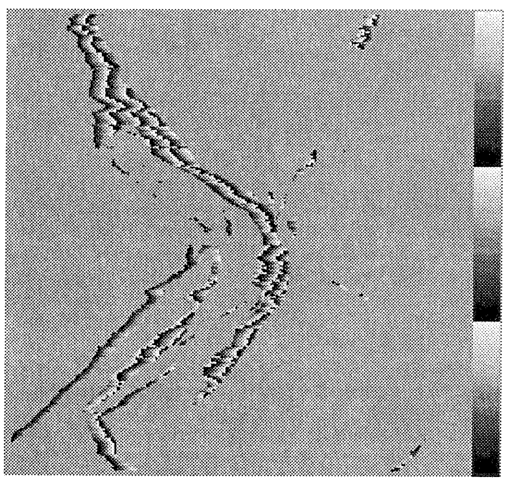
The developed algorithm works on binary images. It is assumed that in a previous step possible foreshortening and layover regions have been identified as areas of interest by thresholding. Once an appropriate initial position between the two stereo images has been determined, the search for match points is restricted to lines, according to the nature of SAR images. At the moment we deal only with those cases where either foreshortening or layover occurs in both stereo partners. The combination of foreshortening in one image and layover in the other image will be the subject of future extensions to the algorithm.

The principle of the binary matching algorithm can be briefly summarized as follows. Matching is performed in two passes. Pass (1) serves to gather information about the number of possible match partners within a certain search area. This information, which is recorded for each pixel to be matched, is then used in pass (2) to establish the actual matching correspondences, according to an overall best fit. The incorporation of knowledge about neighboring pixels, as acquired in pass (1), enables the algorithm to deal with problems such as changing across-track widths, merging layover areas, and speckle noise.

The matching procedure is illustrated in its application to the simulated layover maps from Fig.6. The result of the matching can be seen from Fig.7, where corresponding match points are displayed in the same gray value. For performance evaluation, the match points were converted to terrain height



(a)



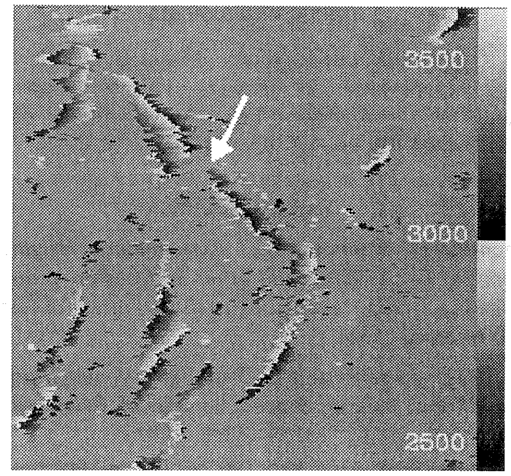
(b)

Figure 7: *The layover maps from Fig.6 after matching. Corresponding match points were assigned the same gray value.*

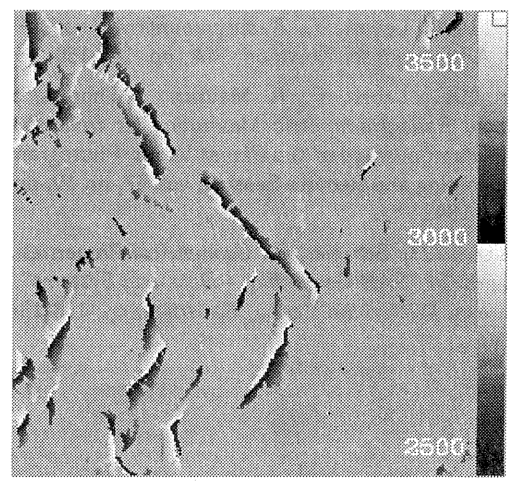
by stereo intersection. The obtained relative height values were then adjusted by an offset, in order to compare them with the corresponding reference DEM. The result is shown in Fig.8, where terrain elevations in active layover areas are encoded as gray values. Elevations in the displayed areas range from about 2500 m to 3700 m. In the central part of the image, both the shape and the height of the reconstructed regions in (a) correspond well to the real terrain in (b). The arrow in Fig.8 (a) denotes an area with layover regions that are separate in one stereo image, but joint in the other one (see Fig.7). Note that the reconstructed active layover areas in Fig.8 are also separated, which means that this situation was properly recognized by the matching algorithm.

4 SUMMARY AND OUTLOOK

We presented a concept for the detection and use of layover information in Magellan SAR imagery. The simulation program and matching algorithm described in the previous section constitute a first step towards the automated terrain



(a)



(b)

Figure 8: *Terrain elevations in active layover areas reconstructed from match points (a) in comparison with the corresponding real terrain (b).*

reconstruction in foreshortening and layover areas, as well as the distinction between them. The matching results obtained from tests on simulated layover maps are encouraging. As a next step, the matching algorithm will be applied to Magellan stereo images, and the results will be compared to the manual measurements carried out by [Connors, 1994]. Then, the DEM derived from same-side stereo images will be input to the simulation program, in order to generate a synthetic image which resembles the corresponding opposite-side SAR image. The simulated image is expected to facilitate the identification of corresponding features in dissimilar SAR images, which is a prerequisite for resolving the remaining ambiguity between foreshortening and layover. Although the aim of the current study is the development of new algorithms for the topographic surface reconstruction from Magellan imagery, the results obtained in this context are not limited to this particular data set, but will also be applicable to other SAR data from both planetary and terrestrial missions.

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