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## AUTOMATED MOLA TRACK REGISTRATION IN MOC AND VIKING IMAGES AND IT'S APPLICATION FOR THE ESTABLISHMENT OF NEW 3-D CONTROL POINTS ON MARS

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### ABSTRACT

In 1998, the Mars Global Surveyor (MGS) started observations of the Martian surface using the Mars Orbiter Laser Altimeter (MOLA) and the Mars Orbiter Camera (MOC). We examine here the potential of MOLA laser altimeter profiles for the creation of a 3-D control point network of the Martian surface.

For the Science Phasing Orbits (SPO) 1 stage, we show that the difference in elevations between crossover points of MOLA tracks within 1km planimetric distance appear to lie within 25m. This result suggests that MOLA has very high positional accuracy both horizontally and a few metres vertical accuracy. We have also performed a comparison of MOLA heights with the old USGS DTM, which was based on the 6.1mb pressure level determined from Mariner 9 UV spectrometer measurements and radio occultation measurements and the 3D control network determined by Wu(1984). The result of this comparison indicates that the old 3D control network is likely to be in error by as much as a few kilometres.

In order to try to improve the global 3D control network, we need to try to register the MOLA altimeter tracks with common features in MOC wide angle and Viking images.

An automatic registration technique has been developed which uses specific features based on the visible edges of surface features such as impact craters and small mountains. Morphological features are difficult to extract from MOC and VO images and are often confused by shadows. This is especially the case with VO images which were taken under a variety of different solar illumination conditions. We applied a hierarchical and heuristic edge searching method to match to the rising point of MOLA tracks. In the next step, the generation of Ground Control Points which could form such 3D control networks will be shown using some sample image resolutions from VO images to demonstrate its future potential with the HRSC instrument on the ESA Mars Express mission which is due for launch in 2003.

### 1 INTRODUCTION

In planetary mapping , one of the most important problems is the determination of a reliable 3 dimensional control point network such that each pixel of a target image can be geographically referenced with respect to a planetary reference surface and the best gravity model available. Photogrammetric techniques have been used to fix x,y,z coordinate in some area using hundreds of images when combined with the best available knowledge of spacecraft position and camera pointing data. These control points must currently be extended by hand to each target image. However it is well known that some of the navigation tracking data, usually from the SPICE kernel, do not have such good quality in certain space missions and the original factors like gravity model to perform photogrammetric techniques have been updated according to further processing of the original mission data. In such cases, the error of 3 dimensional standard points might be propagated within a target image. So the DTM quality from a 3D network will be corrupted through the original error of the control network. We suggest here a new method for building reliable and robust 3 dimensional control network, especially on Mars. This method started from our quality assessment of MOLA(Mars Orbiter Laser Altimeter) data and is based on a new technique for automatic geological feature detection in visible/NIR images and its subsequent automated registration using laser profile measurements. Up until now, most of Martian surface mapping

work has been performed using a 3 D control network constructed by USGS(Wu and Shafer,1984). However this control network has accuracy problems in both horizontal and vertical positioning for the same reasons. So our work should be very useful for new Martian 3 dimensional construction and eventually for terrain model extraction.

We discuss firstly an attempt to assess the accuracy of the MOLA data and then go onto compare this MOLA data against the best available global topographic data-set.. We then describe our new automated crater detection method and conclude with preliminary results from our automated registration technique.

**2 Quality assessment of USGS Mars DTM and MOLA data**

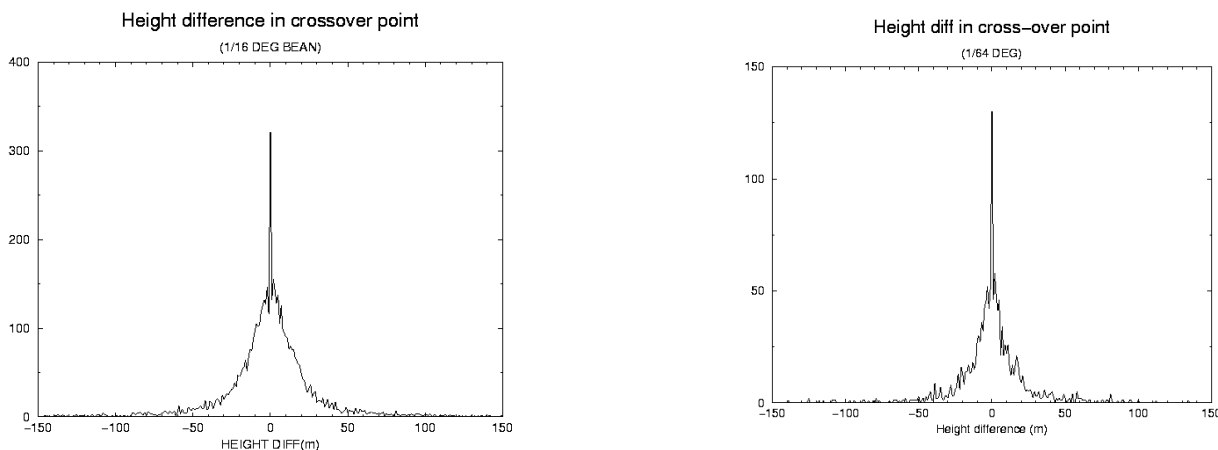
**2.1 Crossover checking of MOLA**

First of all, we need to check the positioning accuracy of MOLA data not only for the vertical measurement data but also for the horizontal position indicator. Theoretically, the mechanism which was used for determining height with MOLA can assure 1.5 meter vertical resolution and 160 meters footprint size (Zuber et al., 1992).

The best way to check positional quality of MOLA was to investigate the distribution of heights around the orbital crossover points. We used two radii to group into cross-over bin-sizes .-1/16 degree and 1/64<sup>th</sup> degree. Even considering the Northern Hemisphere, the target area of SPO 1 stage, is extremely flat (Abaronson et al., 1998), it's quite clear the tracking data quality of MGS(Mars Global Surveyor) and MOLA is enough for the construction of a global 3 D control network

Bin-size (degree)	Number of points	Mean	Standard deviation
1/64	1826	0.018	27.175
1/16	5708	0.324	53.117

**Table 1. Crossover analysis of MOLA SPO-1 data-set**

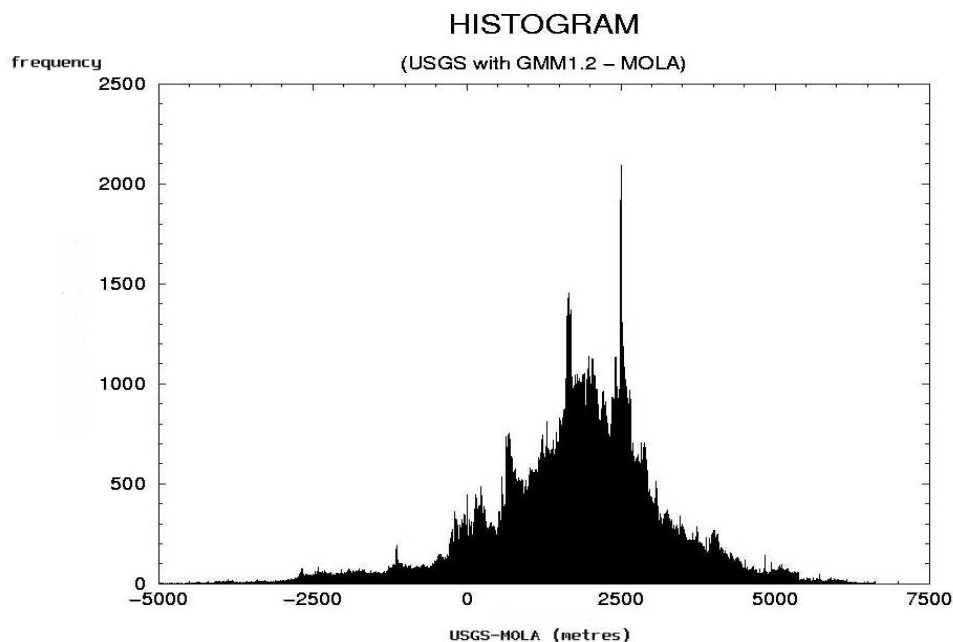


**Figure 1. Histograms of height differences with the Crossover analysis in MOLA SPO 1 stage**

**2.2 Comparison of MOLA data with USGS DEM**

The USGS Mars DEM was based on a global 3 D control network and the 6.1mb pressure level determined from Mariner 9 UV spectrometer measurements and radio occultation measurements (Wu and Shafer, 1984). According to Davis et al. (1992), this network has rms standard deviation 4-5 km horizontally and 800m vertically. So the authors postulated that the USGS DEM had km level error and was not suitable for geological research purpose. Recently Zeitler and Oberst (1999) produced an improved control network using Viking Orbiter images coupled to the best know positions of the Mars Pathfinder area to define new orbital and positional parameters. They published the transformation parameter from old to new network. Because 90% of their landmark coordinates have positional error of less than

1800m, considering the improvement USGS DEM with this transformation, we apply it and the recently defined GMM1.2 Mars gravity model to the USGS DEM. Then a comparison of this “improved” USGS DEM was made with MOLA height values. Figure 2 shows that it still appears that the USGS DEM has km level error. Finally we showed that the USGS DEM has kms level error which originated from the wrong control point which had several hundred meters intrinsic error.



**Figure 2. Height difference histogram between rectified USGS DEM and MOLA**

### 3. Proposal for a new Mars control network construction method

MOLA track profiles have been used for investigations of geological feature such as impact crater as shown by Garvin et al., (1998) and Frey et al., (1999). According to their results, the MOLA track shows a very steep and clear increase at the impact crater boundary, even if in the optical image it appears as a very ambiguous feature. The other motivation is that the most of impact craters can be very well defined by perfect circular shape so that they can be used for positional factor by assigning the radius and the centre point. We therefore propose using automated detection of crater boundaries in MOLA profiles coupled with automated crater detection in VO or MOC images and a novel registration technique to create a new global Mars control network. Such a technique will also be generic in that it should be able to be applied to any extra-terrestrial body.

#### 3.1. Automatic crater detection algorithm

For industrial applications of machine vision, most shapes can be well defined by linear and/or circular features. It is therefore possible to use algorithms for detection of perfectly circular features. The most popular method is based on the Hough transformation (Hough 1960). Ballard (1990) modified this algorithm for circles and other non-straight-line shapes. However, impact craters are natural features. Even with the best quality images, we cannot expect very well defined crater boundaries because of the effect of shadows related to the view and solar illumination angle and the complex structure of the crater boundary itself. Additionally planetary optical images are frequently corrupted by artefacts, and plagued with low illumination angles and systematic noise. Therefore, the modified Hough transform will not work due to this ambiguity in defining its parameter space and a new robust circle detection algorithm is required for altimeter track registration on Mars.

Our approach here is based on work by Thomas and Chan (1987), which uses a regression formula to extract circle radius and centre point from irregularly spaced points. The merit of this algorithm is that it appears to work well with circular features with relatively short arcs. Considering most impact craters are detected as short arcs because of geological multi-structures and shadow effects, it appears suitable for our purpose. However the multi-structure and shadow effects can't be entirely solved only with Thomas and Chan's method so that two additional steps were appended. One is hierarchical median filtering and the other is an arc merge process in the similar circular parameter.

In this modified algorithm, we start by extracting edges using the Canny operator (Canny 1986). After completing a thinning and labelling process, different window sizes of median filtering according to the size of a target circle, different arcs are taken. Then calculating the radius and centre point, an arc merging process is performed. If the processing is completed at this stage, there might be too many candidate circles. So the verification process using the binary image from any edge operator and threshold is required. If the points, which are expected by the candidate circles, can be found in the verification image, the reliability of the expected circle is increased. The arc, which has a higher reliability value than certain criteria, will be removed from iterative processing. Figure 3 shows the overall algorithm and the applications of this algorithm to a Mars image extracted from 1/256 degree resolution MDIM (Mosaicked Digital Image Model) and to MOC (Mars Orbiter Camera) wide angle image, which has 250 metres resolution, are shown in Figure 4. Currently it is impossible to detect impact craters perfectly, mostly because of very shallow impact crater, multi-structure, shadow effects and the uncertainties arising from complex geological features. The solution for higher detection accuracy is to find an edge with high reliability.

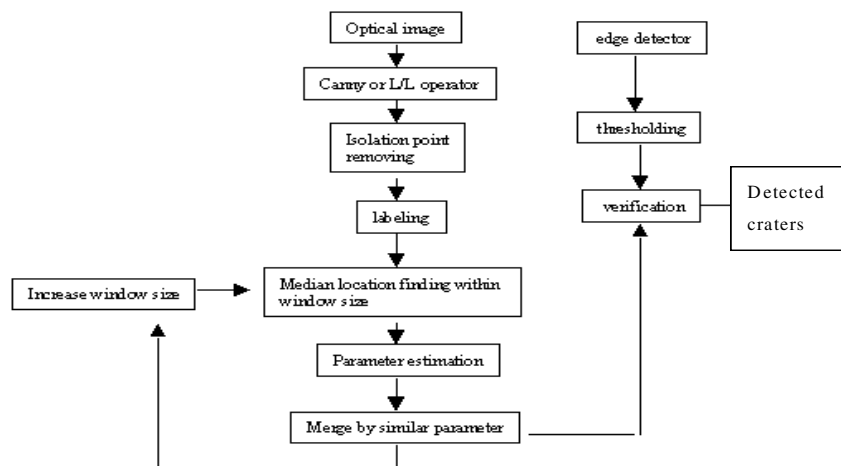
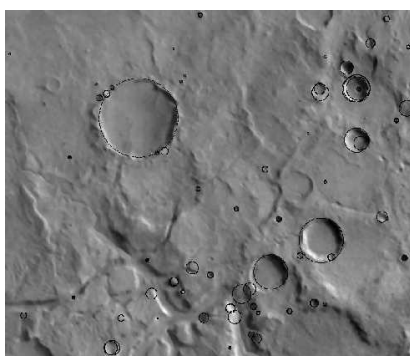


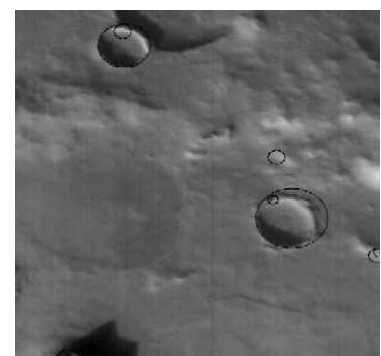
Figure 3. Schematic diagram showing the crater detection algorithm processing steps



(a) An example in complex geological feature from MDIM 1/256 degree resolution (224-2254W, 24-25N)



(b) An example in flat region from MDIM 1/256 degree resolution (78-75W, 22.5-25.0N)



(c) MOC wide angle image 242m resolution (center : 258.49W, 49.45S)

Figure 4. Application example of crater detection

### 3.2. Detecting impact craters in MOLA ground tracks

As seen in Figure 5, most MOLA track profiles on impact craters can be well distinguished, even when there are x or y directional shifts due to imprecision in the pointing knowledge of the VO or MOC image compared with MOLA. We suggest finding unique features using the local 1<sup>st</sup> derivative minimum of the MOLA profile. This point will be used as a

reference point for the next step. The main characteristic of the impact craters on MOLA data are two things. One is the height difference compared with a nearby reference surface and the other is location of the steepest boundary. Applying different sizes of templates around these local 1<sup>st</sup> derivative minimum points, and checking the similarity, the crater can be detected. We used the 300 metres depth template compared with the normalized reference, which is made by the relative height above a first order regression surface. Of course, the difference sizes of template should be applied to the 1<sup>st</sup> derivative minimum point repeatedly. If a very clear crater is detected, the height values within the detected one must be replaced with the reference height for a further crater detection stage.

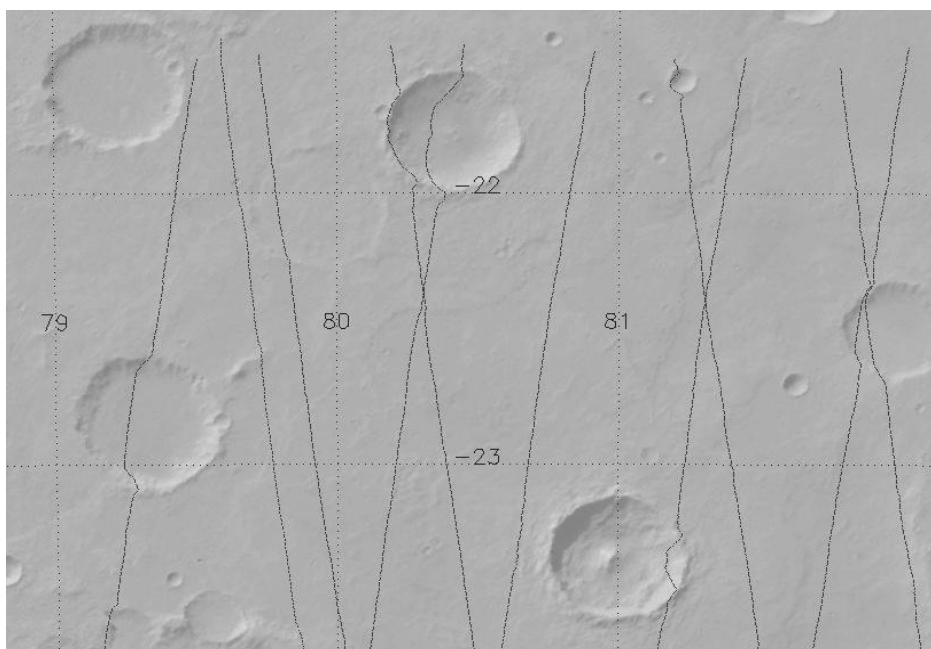
### 3.3 Automated MOLA-VO or MOLA-MOC Matching

Measuring the length to the height transition point from the minimum depth in the MOLA track, and comparing it with detected circle's radius in optical image, we can try to determine the x,y directional shift of optical images- in other words, optimal matching point. However, the wrongly defined impact crater can produce distortions during track registration. One method to avoid such problems is to use fuzzy logic with simple triangular membership function (Earl 1999), whose domain width is related with the estimated crater size. The evaluation method is also very simple. Within some search window ,

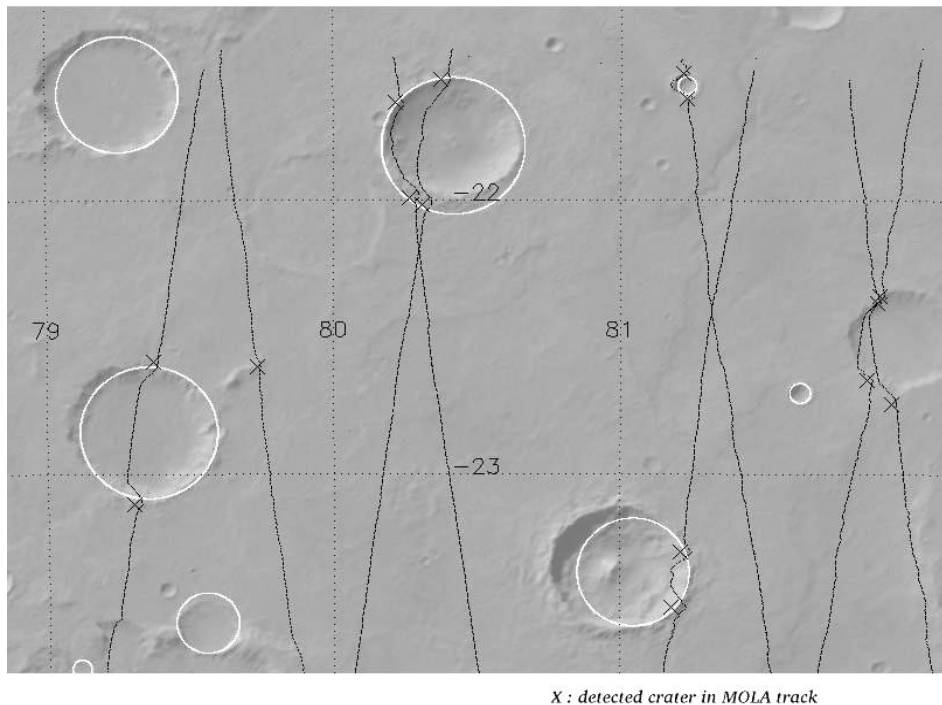
$$F(\mu_{mola}, \mu_{image}) = \frac{1}{i * j} \sum_{x=0}^i \sum_{y=0}^j \min(\mu_{mola}, \mu_{image})$$

( F : the evaluation function for the similarity,  $\mu_{mola}$  : the triangular membership function of the detected impact crater on MOLA,  $\mu_{image}$  : the triangular membership function of the detected impact crater on image, i : search window size in x direction, j : search window size in y direction)

In Figure 5, a comparison is shown between manual altimeter track registration and the proposed automatic method. Within the search window, if a crater can't be detected, we used the x,y shift of the previously matched track like the last two tracks shown in Figure 5-b. The mean x,y shift difference in two images is 1-1.5 km. In this way we can calculate the accuracy of the automatic registration method.



(a) Crater detection example using a manual method



(b) Crater detection example using automated registration technique

Figure 5. MOLA track registration comparison of manual vs. automated

### 3.4 A modified method for automatic crater detection for mapping

If the impact crater around the MOLA track's crossing point can be detected, it will be a more reliable 3 D landmark because the  $x,y,z$  coordinate of such a feature can be cross-checked using two MOLA track. We ran our crater detection program in the area bounded by 79-82E, 23.52-21.5S as shown in Figure 5 and found such a crater. It will then be possible to detect as many impact craters close to these MOLA crossover points, if we apply the crater detection algorithm on the Mars global image. However, because high latitude images have impact craters, which are seriously distorted by camera angle, an improved crater detection algorithm for arbitrary elliptical shape needs to be developed.

### 4. Future improvements

Currently, we are concentrating on trying to improve two aspects of the current method: a) improvements in detecting the impact crater's boundary, b) improving crater detection using more generalized shape models, such as ellipses rather than circles. Most of the registration errors originate from the detected crater shape's distortion. Large impact craters are not circular shaped and smaller (km) sized crater detection suffers from shadowing effects.

### 5. Conclusion

We assessed the horizontal and vertical accuracy of MOLA tracks using crossover analysis and found that positioning accuracy of MOLA is good enough to be used to register optical images in order to create a new 3D control network construction.

An automated registration procedure was demonstrated, which can be used to detect craters in both MOLA and optical images and then register them using a matching method with a simple fuzzy membership function. However, this procedure cannot currently be applied globally for a fully automated registration procedure as there are some problems with the automated crater detection algorithm, due to parameter estimation, the use of a multi-scale median filter and arc merge. Uncertainties, originating from shadow boundaries, multi-structure impact craters and shape distortion of craters will result in poorer registration. Currently this tool is semi-automated in that some manual verification and editing is required whilst we try to improve the detection and matching algorithm for a fully automatic track registration.

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**Reference**

- Abaronson O., Zuber M.T., Neumann G.A., Head J.W., 1998, Mars : Northern hemisphere slopes and slopes distribution, 25(24), pp.4413-4416
- Ballard D.H., 1981, Generalizing the Hough transform to detect arbitrary shape, Pattern Recognition, 13(2), pp.111-122
- Canny J.F., 1986. A computational approach to edge detection, IEEE Trans. PAMI, 8(6), pp. 679-698
- Davies M.E., Baton R.H., Wu S.S.C., 1992, Geodesy and Cartography in Mars, ed. Keitler H.H, Jasky B.M., Snyder C.W., Marthew M.J., pp.321-342, Univ. of Arizona press, Tucson
- Earl C., 1999, The Fuzzy System handbook, pp. 130-149, Academic Press, New York
- Frey H., Sakimoto E.H., Roark H., 1999. Discoverey of a 450km diameter, multi-ring basin on Mars through analysis of MOLA topological data, Geophys. Res. Lett. 26(12), pp. 1657-1660.
- Garvin J.B., Frawley U., 1998, Geomatic properties of Martian impact crater , Geophys. Res.Lett, 25(24), pp.4405-4408
- Hough P.V.C., 1960, Method and means for recognizing complex pattern U.S Patents 3 069 654
- Thomas S.M., Chan Y.T., 1989, A simple approach for the estimation of circular arc center and its radius, Comput. Vision Graphics Image Process, 45, pp. 362-379
- Wu S.S.C., Doyle F.J., 1990, Topographic Mapping, in Planetary mapping, edited by R.Greeley, and R.M.Batson, pp.169-207, Cambridge University Press, Cambridge, U.K
- Wu S.S.C., Schafer F.J., 1984, Mars control Network, American Society of Photogrammetry, 50<sup>th</sup> Annu. Meet. (2), pp. 456-464
- Zeiter W, Oberst J., 1999. Mars Pathfinder landing site and the Viking control point network, 26(12), pp. 1657-1660.
- Zuber M.T., Smith D.E., Solomon S.C., Muhleman D.O., Head J.W., Garvin J.B., Abshire J.B., Bufton J.L., 1992, The Mars Observer Laser Altimeter investigation, J.Geophy. Res., Col.97(E5), pp.7781-7797