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Registration of MOLA profiles to HRSC DTMs: Prospects for mapping of seasonal ice cover variations at the Martian poles

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Abstract

We propose the co-registration of laser profiles to high resolution Digital Terrain Models (DTMs) as an approach for retrieving surface elevation changes at the poles of Mars. The edge of this method is validated using reprocessed and simulated Mars Orbiter Laser Altimeter (MOLA) profiles. The ultimate goal is to apply this method to MOLA and HRSC DTMs to generate seasonal and long-term elevation change time series at the Martian poles with high spatial and temporal resolution.

1. Introduction

The dynamic growth and retreat of polar CO_2 frost at the Martian poles was discussed by several papers [1, 2, 3]. The accurate measurements of seasonal and long-term elevation and volume changes can serve as important constraints in Mars climate models and can help tap into the density evolution of the CO_2 snow once combined with gravity measurements. The traditional approach to this problem is the crossover analysis, but this method may suffer from significant interpolation errors when spacing between footprints is large, also residual pointing, timing and orbit error may translate into lateral shifts of the laser profiles and undermine the results. Here, we propose and validate the registration between laser profiles and high resolution DTMs from stereo pairs as a solution to these problems which makes the most of information inherited in both data types.

2. Data

2.1 MOLA records

The MOLA Precision Experimental Data Record (PEDR) dataset features a total of 8505 profiles, acquired in the mapping and extended phases from February, 1999 to May, 2001, which spanned approximately a full Martian year and can enable us to observe the surface height change due to CO_2 seasonal condensation and sublimation phenomenon [1]. The PEDR dataset was processed with older orbit trajectory model and Mars rotational model by GSFC (Goddard Space Flight Center) dating back to 2003. Therefore, we have incorporated a refined orbit model from [4] and IAU2015 Mars rotational model [5] in the MOLA geolocation reprocessing. Meanwhile, to account for the special relativity effect, the pointing aberration correction has also been taken care of in the reprocessing [6].

2.2 HRSC DTM

The High Resolution Stereo Camera (HRSC) is a pushbroom camera onboard of the European Space Agency (ESA) spacecraft Mars Express. The HRSC DTM adopted here has a grid size of 75 m and covers a region entailing a range of fine features like craters, volcano and plains [7]. Visual inspection indicates that no spikes and large patches of interpolated pixels exist.

3. Methods

3.1 Height change estimation

Three methods have been proposed to retrieve the height differences at the crossovers and tested using simulated MOLA profiles:
X_analysis: Using crossover analysis to first locate the position of the crossovers, interpolating the heights to the crossovers from ascending and descending pairs, and finally subtracting one from another to retrieve the change information at the crossovers.
2D_align: Laterally registering the laser profiles to DTMs to account for lateral shifts of the profiles [8] and then using X_analysis to resolve the height differences at the crossovers.
3D_align: Aligning the laser profiles to DTMs in lateral and vertical direction [8] and derivation of the height difference at each crossover as the difference

in vertical corrections for the two intersecting profiles.

3.2 Simulation of MOLA dataset

To evaluate the performance of these three proposed methods and to quantify the impacts of interpolation and lateral shifts of the laser profiles, we simulate the MOLA profiles by aligning them to the HRSC DTM first, and then assign the DTM heights at the registered locations to the original ones but with lateral positions stayed unmodified which preserves as shifts with respect to (w.r.t.) the DTM. Thus, the theoretical height differences at the crossovers should be 0, and any deviations should be interpreted as pure errors, e.g. interpolation error or lateral misalignment error of the profiles.

4. Results

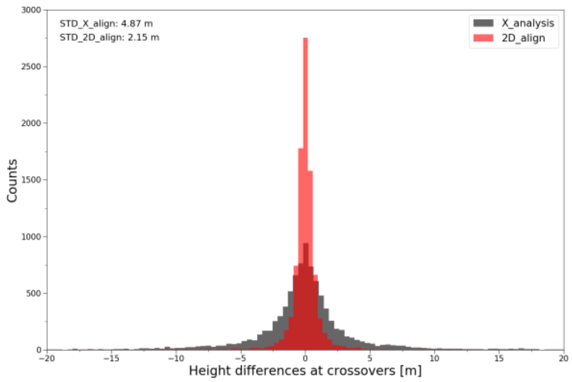

Figure 1: Histogram of the crossover height differences by “X_analysis” and “2D_align”, while the standard derivation (STD) of the values of “3D_align” is almost zero, thus it is not shown here.

For the results over the simulated MOLA profiles, the STD of the height differences went down from ~4.9 m of “X_analysis” to ~2.2 m of “2D_align” and ultimately to ~0 for “3D_align” as shown in Figure1. The lateral corrections of each profile for “2D_align” and “3D_align” are nearly identical with marginal differences. In the context of this simulation experiment, ~4.9 m represents a combing impact of profile alignment error and interpolation error, while the value of ~2.2 m only stands for the errors exerted by the interpolation. This comparison validates the superiority of “3D_align” method over the “2D_align” and “X_analysis” methods when profiles do not align perfectly and the along-track sampling distance of the laser profiles can be relatively large (~300 m in the case of MOLA).

5. Summary

We show the feasibility and merits of the 3D registration method in the application of retrieving height changes at crossovers: (1) it can utilize information from all of the points of the profile and thus can avoid the errors introduced by interpolation as in the case of “2D_align” and (2) it can naturally correct for any residual lateral shifts of the laser profiles w.r.t. the overlapping DTM as in the case of “X_analysis”.

6. Outlook

As a set of new high resolution HRSC DTMs have recently become available that covers the entirety of the South Polar Residual Cap (SPRC) [9], we can take advantage of this great dataset, the “3D_align” registration method and possible spatial gridding and temporal binning procedures to derive high resolution elevation change map of the south pole of Mars which can shed light on the local variability of the CO_2 seasonal redistribution. Also, combined with SHARAD radar altimetry, the long-term elevation change series can become possible [10].

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