MULTI-BEAM ALTIMETRIC CROSSOVERS FOR THE PRECISION ORBIT DETERMINATION OF THE LUNAR RECONNAISSANCE ORBITER.

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Introduction The use of altimetry as a supplemental data during the orbit determination process has proved beneficial for both the calibration of altimeter instruments [1] and the quality of reconstructed orbits [2]. Such data are anticipated to be especially important for the LRO mission [3], because of positioning requirements, large Moon gravity anomalies, the lack of any tracking on the far side, and the limited precision of the S-band telecom system. The Lunar Orbiter Laser Altimeter (LOLA) onboard LRO is a multi-beam instrument, measuring at 28Hz the roundtrip time-of-flight of five laser pulses [3].

The slow rotation of the Moon leads to an unusual crossover spatial distribution. The conventional (single-beam) use of those multi-beam shots (25 effective crossovers for each ground track intersection) was shown to improve the orbit recovery significantly[4]. However, very few occur in non-polar regions (about 4%), and most of those have shallow intersection angles. This is a poor geometry for the single-beam crossovers, as no cross-track information is available. Here, we explore how the cross-track information inherently present in the LOLA altimetric swaths can be used to provide stronger orbital constraints.

Method: Out of the 110,000+ track intersections which occur over a lunar month (here March 2009 in a former LRO predicted trajectory), we only consider the 4365 in non-polar regions with angles shallower than 10° (Figure 1). For each crossover, we sampled LOLA measurements with simple artificial fractal topography.

From a single crossover, we can only estimate the relative displacement between those two swaths. This is done by minimizing the altitude misfit of the two altimetric swaths. Each track's altimetric data points are interpolated onto the other's, and the sum of the squares of the differences is minimized.

In a fully dynamic setup, within the Orbit Determination program used at GSFC (GEODYN II, [5]), potential biases should be removed. The perturbing displacements on both tracks of each crossover are calculated from a set of orbital perturbations over the chosen lunar month. The use of the same initial orbit recovery errors as in [4] lead to rather poor results, which shows that the current technique is to be applied after conventional crossover techniques have first been used to improve the orbits. Here, we use randomly generated orbital perturbations, with amplitudes consistent with the results of [4], i.e. ±50m in cross-track and along-track and ±5m in radial (Figure 2). Figure 3 (dashed line) shows the cumulative histograms of the relative displacements to be solved in our simulation.

Results: The displacement estimation is done in a local Cartesian frame, with the X direction being nearly cross-track, and the Y direction being parallel to the along-track (bisecting the tracks). As shown in Figure 3 (thick solid line), the errors are significantly reduced after the estimation process: about 80% of the cross-track errors are within 10m, 90% of the along-track within 10m and 95% of the radial within 1m. The pre-adjustment numbers were ~25%, ~30% and ~17%, respectively.

The Z direction is the best determined. This is not surprising given the large intersection area of the near-adjacent swaths: a small radial offset translates into a large increase in the cost function value. The ambiguities in the horizontal directions are larger, and although the noise level does not impact the results much (dotted line), more realistic artificial topographies might be helpful. Indeed, the X direction (nearly cross-track) is the most poorly constrained, because of its small altitude contrast compared to the Y direction (along-track or anti-along-track). The future addition of craters in our simulations should mitigate this problem.

These estimated relative displacements will be used as constraints in the Precision Orbit Determination process, within the GEODYN II program, and orbital errors as well as altimeter pointing biases will benefit from these multi-beam constraints. Here, in order to illustrate the potential benefits to the LRO orbital recovery, we used the obtained relative displacements to invert for the original orbital perturbations shown in Figure 2. The inversion scheme is very simple. Each direction is processed separately, and a time series is estimated sequentially with a least-squares scheme to fit the 'observed' relative displacements. This works very well for the radial direction (Figure 4), with maximum residuals of ~1.3m, and a residuals RMS of ~30cm. The along-track and cross-track time series are currently poorly recovered, due to the X direction issues discussed above. Nevertheless, shorter time intervals ˇwithin the example lunar month show better recovery, and show potential for future improvements.

Summary: The altimetric crossovers presented here, which use the cross-track information of the LOLA data, will help improve the accuracy of the reconstructed orbits of the LRO spacecraft. Although a more conventional use of the altimetry data in the orbit determination process should satisfy the positioning requirements, the global reference frame to be created from LRO Radio Science and Altimetry investigations will benefit from the improved accuracy of the "swath crossovers". In this non-dynamical simulation, we showed that the numerous non-polar low-angle crossovers have the potential to significantly reduce the orbital errors.

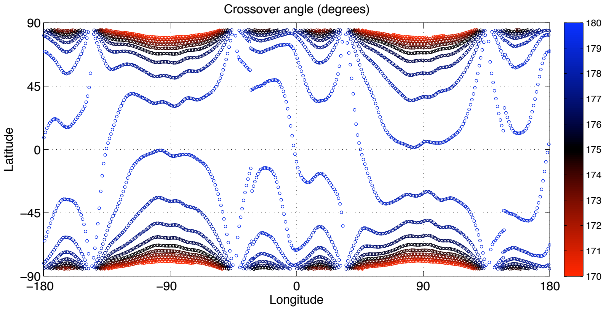

Figure 1. Location of the crossovers considered in this study (month of March 2009 in the Mission Baseline Ephemeris v5.1). The color scale indicates the angle difference of the two intersecting tracks. They are all ascending-descending crossovers, with shallow intersection angles.

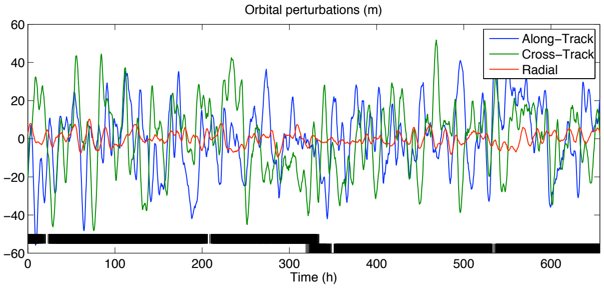

Figure 2. Orbital perturbations (i.e., initial orbital errors with respect to the true trajectory) over the study period. The vertical black segments at the bottom indicate the crossover times.

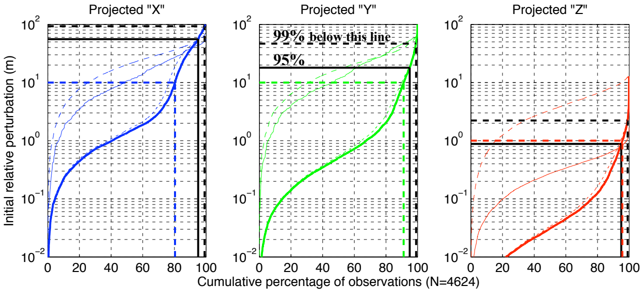

Figure 3. Cumulative histogram of the relative perturbations. The various lines show: initial orbital error (dashed), errors after displacement estimation (thick solid), same with noise (dotted), and errors after time series estimation (thin solid).

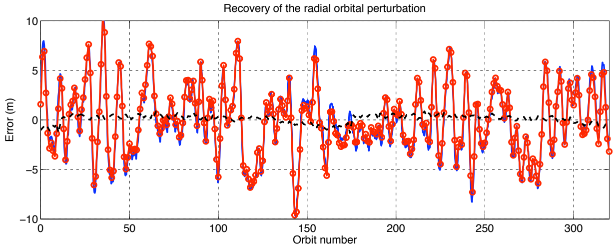

Figure 4. Radial orbital perturbation time series: initial (blue), recovered (red), and residual (black).

References:

[1] Lutchke et al. (2005), *GRL, 32*. **[2]** Neumann et al. (2001), *JGR, 106*. **[3]** Chin et al. (2007), *Space Sci. Reviews, 129,* 391-419. **[4]** Rowlands et al. (2008), *J.Geodesy*. **[5]** Pavlis et al. (2008), GEODYN II Operations Manual.