Origins Spectral Interpretation Resource Identification Security-Regolith Explorer

MLN-FDS F6

(OSIRIS-REx) Project

Final Test Report

Revision Final

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OSIRIS-REx Project
MLN-FDS F6 Final Test Report

SIGNATURE PAGE

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CM FOREWORD

This document is an OSIRIS-REx Project controlled document. Changes to this document require prior approval of the OSIRIS-REx Project CCB Chairperson. Proposed changes shall be submitted to the OSIRIS-REx Project Configuration Management Office (CMO), along with supportive material justifying the proposed change.

In this document, a requirement is identified by “shall”, a good practice by “should”, permission by “may” or “can”, expectation by “will”, and descriptive material by “is.”

Questions or comments concerning this document should be addressed to:

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REVISION LOG

Revision	Paragraphs affected	Change Description	Release Date
Draft	All		Sept 19, 2016

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1. Introduction

1.1. Purpose

This document is the Maps for Landmark Navigation-Flight Dynamics System (MLN-FDS) F6 Final Report.

1.2. Scope

- This test report includes performance against test objectives, planned and actual activities, planned and actual requirements verification summary, and data product verification. The test report also includes problems encountered during test and disposition of all TDRs, verification status with corresponding TDRs and plan for resolution along with overall lessons learned from the test.

The objectives/success criteria for F6 are:

- Test showing that the DRM provides sufficient data to generate 35cm GSD shape model

2. MLN-FDS F4 Test Summary/Results

2.1. Overview

The F6 test starts with the output from the F4 test and was broken into two sections with three major blocks:

- Baseball Diamond
    - Block: Adding Images,
    - Block: Evaluation & Fix
- Equatorial Stations
    - Block: Increase Resolution ZMap
    - Block: Adding Images,
    - Block: Evaluation & Fix

As planned the F6 test was not conducted with a one-to-one correlation between the test procedures and the work required because many procedures must be done numerous times with different data to build the shape model.

The processes followed how the shape model would be generated during actual mission operations. The initial F4 shape model was used as a base. Images were brought in and maplets generated to improve the resolution of the shape model.

The initial set of maplets was from the F4 test or 75 cm shape model. After the last Baseball Diamond images were downlinked the ALTWG/SPC delivered a 35 cm DTM to FDS within the required fourteen days.

The ALTWG/SPC team generated the 18 cm maplets that were subsampled to generate the 35cm DTM with higher fidelity.

The decision was made to not include the Equatorial Stations image set, thus ending the test earlier. The F4 test results demonstrated the requirements for the 35 cm shape model were satisfied at the end of Preliminary Survey. This test showed the resolution improvements from the Baseball diamond images were minimal. All parties agreed that adding in the Equatorial Stations would not improve the shape model delivered after the Baseball diamond.

2.2. Test Discrepancies Reports Status

Table 21contains the status for the TDRs that were opened during test execution. All TDRs can be found on ODOCS in the “OSIRIS-REx 09.0 Ground Systems/MLN-FDS/F6 Run For Record” folder.

Table 21 TDR Status

TDR #	Title	Status
MLN-FDS-003	SPOC to ALTWG ICD	Closed
MLN-FDS-005	MRD-693 should be 14 days past Detailed Survey	Open
MLN-FDS-006	MapCam Images pointing errors	Closed
MLN-FDS-008	Early F6 Test Termination	Closed
MLN-FDS-009	Incomplete Map Data	Closed

2.2.1. MLN-FDS-003 SPOC to ALTWG ICD

Problem: The SPOC to ALTWG ICD, needs to be approval prior to the ALTWG shape Model verification activities or approximately May 16, 2016.

Resolution: Closed. The ICD has been approved by all parties.

2.2.2. MLN-FDS-005 MRD-693 should be 14 days past Detailed Survey

Problem: MRD-693 specifies the 35 cm Shape Model be delivered 14 days past the Baseball Diamond. The delivery date should be 14 days past Detailed Survey

Resolution: Open. Modifying MRD-693 via the Technical Change Request (TCR) process. When the TCR is approved this TDR will be closed.

2.2.3. MLN-FDS-006 MapCam Images Pointing Errors

Problem: Unexpectedly large pointing/position errors for the MapCam images have been identified in the Baseball Diamond segment for the F6 test. These would inject wrong spacecraft pointing values, and could degrade the topography if included in the developing shape model. Pointing should be about 1/2 mrad and we are seeing errors that would equate to about 10 mrad, well outside of design specifications. This equates to position errors on the order of 100's of meters. This needs to be corrected before going on.

During the F1 and F3 tests, we used images from Shape 3 that were generated using the PolyCam/MapCam during Baseball Diamond, as per the DRM. For F6, we changed the Baseball Diamond CK (pointing) kernels to allow for 1/2 of the stations to be off-nadir. However, image times were not updated for the MapCam observations. The PolyCam images were made with the new kernels and imaging times. However, the MapCam images appear to have been created with the old imaging times (as confirmed by Kenny) and the old nadir-only Baseball Diamond kernels.

Resolution: Closed. The following actions were taken:

1) Identify problem kernels.
2) John Kidd to determine the image time of each of the images. "DetailedSurvey_BaseballDiamond_HybridDesign_MapCamImageTimes_20160622.txt"
3) Kenny Getzandanner to regenerate the MapCam images.
4) Replace the testing kernels in the test directory.MLN-FDS-006
5) Delete the old PS MapCam images from the model and move flawed image set to archive directory.
6) Re-ingest corrected images into the model. Continue the test with step 4.1.

Have MapCam images generated similar to what was done with test F1. This would require us to ignore the time it takes to switch between the PolyCam and the MapCam cameras. We would need John Kidd to figure out the image time of each of the images. Kenny Getzandanner would have to regenerate the MapCam images (he has confirmed this would not take long — small number of images).

1) Review results from problem analysis to confirm root cause and corrective action. Discussed at SPC status meeting 6/22/16 9:00 AM MST. Root cause confirmed
2) Disposition kernels identified as flawed for any future use (may have residual value) of properly identified. These are currently in quarantine.
    a. Contact R. Olds at LM to make sure he is aware of problem. Disposition 10/5/16 – timing was incorrect kernels were fine. LM and Ryan do/ did not use these products.
3) Provide impact to timeline and any requirements.
    a. Present impact is 16 days based on receiving corrected images on 7/8/16. Restart accomplished per timeline and test completed ontime.

2.2.4. MLN-FDS-008 Early F6 Test Termination

Problem: The MRD states the shape model will be delivered after Baseball Diamond. In the original DRM Baseball Diamond occurred at the end of Detailed Survey, so the original plan of F6 was to deliver the shape model after Detailed Survey. When Baseball Diamond was moved to occur before the Equatorial Stations, we failed to notice the distinction between end of Baseball Diamond and end of Detailed Survey in the MRD. Hence, the F6 procedures included the Equatorial Stations, even though the delivery needed to take place before the Equatorial Stations began.

This change will have little impact on the F6 test. The equatorial stations were included to bring the number of spacecraft observations stations at every point on the surface from 2, to 3 or more. However, the shape model has been very well behaved and already meets requirements. While the equatorials stations will improve the shape model, the current shape model will be sufficient for navigation purposes.

Resolution: Closed

1) Do not execute tasks 4.2.2, 4.2.3, 4.2.4.
2) There is no impact to model delivery or process.
3) Update Documentation to properly capture as-run

2.2.5. MLN-FDS-009 Incomplete Map Data

Problem: During the process of completing the Shape model it was partitioned into 4 sections to accelerate processing. During the setup of the directories including the input files two input files were inadvertently left out. After processing the subsections and bringing the partitions back together, gaps in the surface of the shape were noted. The defect was traced to the regions covered by these files.

Resolution: Closed

1) The cause of the gaps was due to the lack of data left out in the manual process of setting up the files and directories and was not a failure of the software or a defect in the procedure.
2) The directories and files were rebuilt and the process quickly re-run resulting in a shape that included all available information.
3) Update Documentation to properly capture as-run.
4) Evaluate the development of additional instructions/scripts to generate or check for complete and proper creation of data directories and files for multi partition processing.
5) Make determination if additional scripts/programs should be developed to support facilitate multi-partition processing.

The procedures for multi-partition processing are one of the least developed in SPC. The generation of ZMAPS and using EXPORT/IMPORT is a more advanced feature and has had little testing beyond the minimum showing the code works.

We identified that this was an operation that could be done manually as-needed with satisfactory results and did not have the criticality to justify the resources to create, test and validate the tools.

There is sufficient justification due to the lack of maturity that additional effort should be placed on this aspect if SPC is used beyond the 35 cm shape model (i.e. we are used for NFT). In sum, for F6, we are okay. If we have additional requirements, we need additional testing on the multi-partition processing

3. Requirements Verification Summary

Table 31shows the verification status of the MLN-FDS F4 applicable requirements. There were no de-scoped requirements

Table 31 Requirement Verification Status

Req. ID	Requirement Description	Verification
MRD-687	The Ground System shall, for > 80% of the asteroid surface, produce a set of DTMs at < 0.35 m in ground sample distance (sample resolution). Note: Ground sample distance is defined as the sample spacing of the surface in m/pix.	PASS
MRD-689	The Ground System shall, for > 80% of the asteroid surface, produce a set of DTMs with post-fit residual RMS < 0.18 m (1-sigma) for each maplet. Note: Post-fit residual of a maplet is defined as the (pixel, line) difference between predicted model and observed images of the maplet.	PASS
MRD-691	The Ground System shall, for > 80% of the asteroid surface, produce a set of DTMs with a 3D RMS accuracy < 0.75m (1-sigma). Note: Accuracy is defined as the absolute uncertainty of a point with respect to the origin of the asteroid centered fixed frame.	PASS
MRD-693	The Ground System shall provide the global 35cm DTM product to FDS within 14 days of downlink of all Detailed Survey "Baseball Diamond" OCAMS and OLA data.	PASS

NOTE: 80% percent of the asteroid surface is determined by the following process:

- Run SPC “residuals” to define which landmarks have the lowest residual
- Remove the 20% worse landmarks
- Extract the “Central Vector” of the remaining landmarks to form a “Point Cloud”
    - Simple file of x, y, z vertices
- Compare this point cloud with the truth model
    - It evaluates only those vertices
    - 5cm GSD shape model is evaluated every 2.5m

NOTE: Evaluation of landmarks that meet the requirement will be done as part of the test. Part of evaluation is need for waiver or update of MRD 689 requirement

3.1. MRD-687, MRD-689, and MRD-691 Summary of Verification Evidence

The requirements state:

- The Ground System shall, for > 80% of the asteroid surface, produce a set of DTMs at < 0.35 m in ground sample distance (sample resolution).

Note: Ground sample distance is defined as the sample spacing of the surface in m/pix..

- The Ground System shall, for > 80% of the asteroid surface, produce a set of DTMs with post-fit residual RMS < 0.18 m (1-sigma) for each maplet.

Note: Post-fit residual of a maplet is defined as the (pixel, line) difference between predicted model and observed images of the maplet.

- The Ground System shall, for > 80% of the asteroid surface, produce a set of DTMs with post-fit residual RMS < 0.18 m (1-sigma) for each maplet.

Note: Post-fit residual of a maplet is defined as the (pixel, line) difference between predicted model and observed images of the maplet.

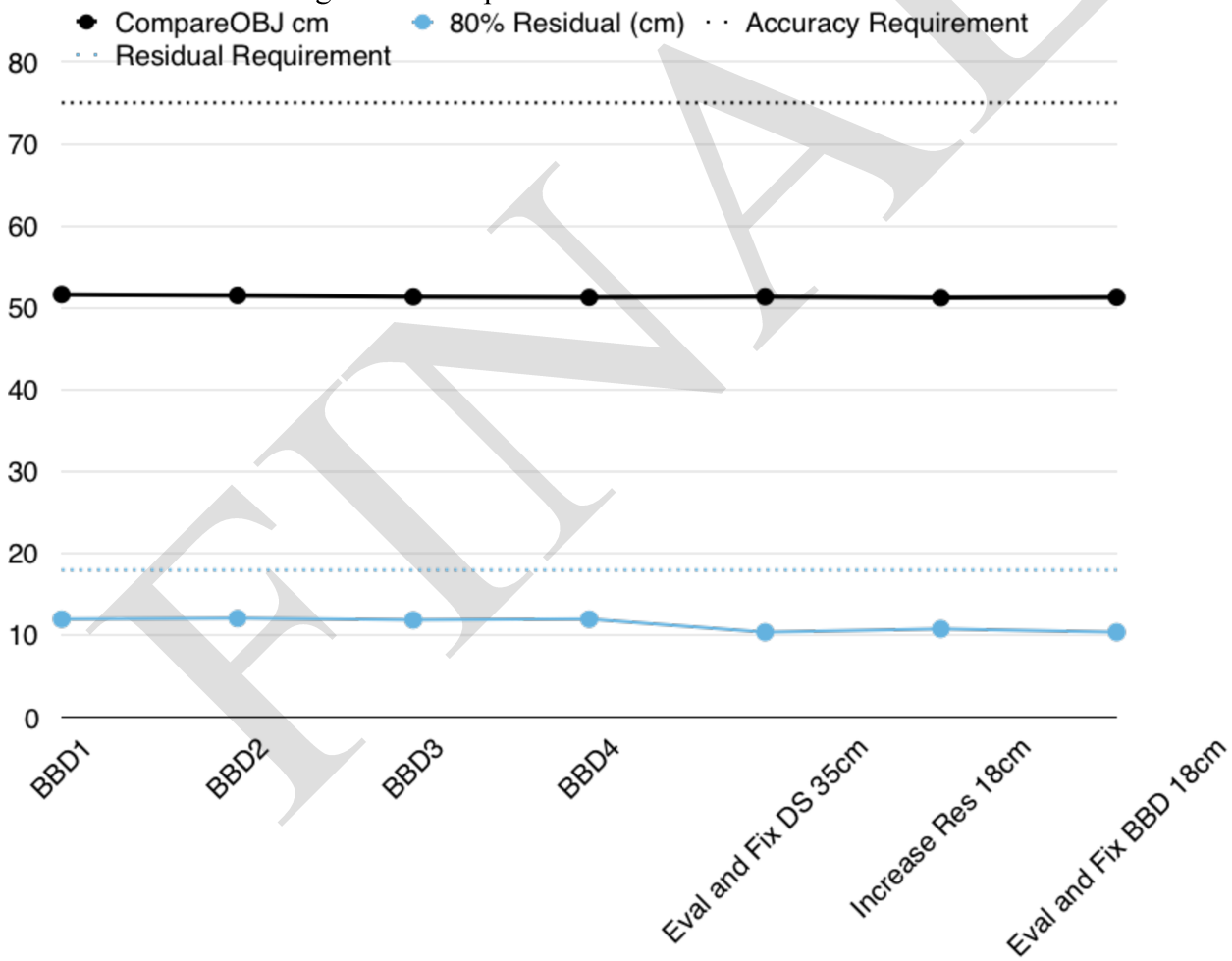

Figure 31 F6 35cm Shape Model Results

Figure 31 shows that the accuracy and residual requirements were met. The X axis is the step of processing from which the results were taken. The black line shows the cm error calculated

between the truth model and the generated model, which decreases slightly from its starting point (end of test F4). The requirement is the dotted black line, so the requirement was pass by a large margin.

The blue color is the residuals in centimeters of the agreement between all of the images and the landmarks. To solve for this, we calculated the average error between where each pixel/line solution of the landmark would be with the position the landmark is in the model. We compute the RMS for each landmark, then sort them to see what the RMS threshold is at the 80% level. The requirement is 17 cm (dotted line), and the model's performance (solid) continually improves.

Figure 31 shows that 100% of the surface was covered at 35 cm. The figure also shows the accuracy of 3D RMS < 1m (1-sigma) also exceeded requirements as shown below:

- CompareOBJ 100%: 52.0 cm
- CompareOBJ w/ Translate/Rotate: 33.6 c
- Point Cloud over 80%: 53.7 cm

3.2. MRD-693 Summary of Verification Evidence

The requirement stated: The Ground System shall provide the global 35cm DTM product to FDS within 14 days of downlink of all Detailed Survey "Baseball Diamond" OCAMS and OLA data.

The execution log recorded the actual calendars days it took to complete the 35 cm DTM, steps 4.1.4 thru 4.1.6 in the F6 test procedure. It took seven days, Figure 3.2-3.6, to complete those steps.

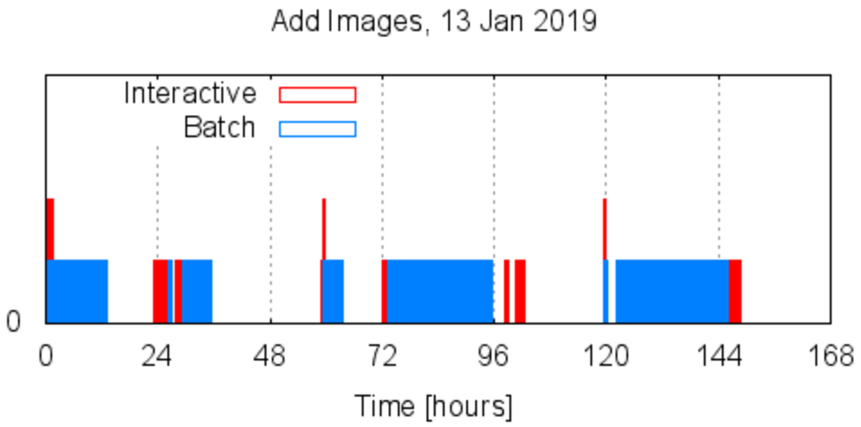

Figure 32 Image Processing Time for Jan 13 images

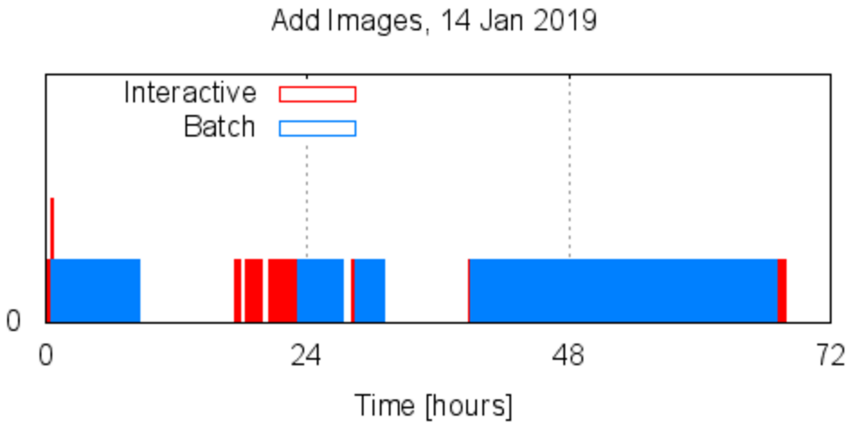

Figure 33 Image Processing Time for Jan 14 images

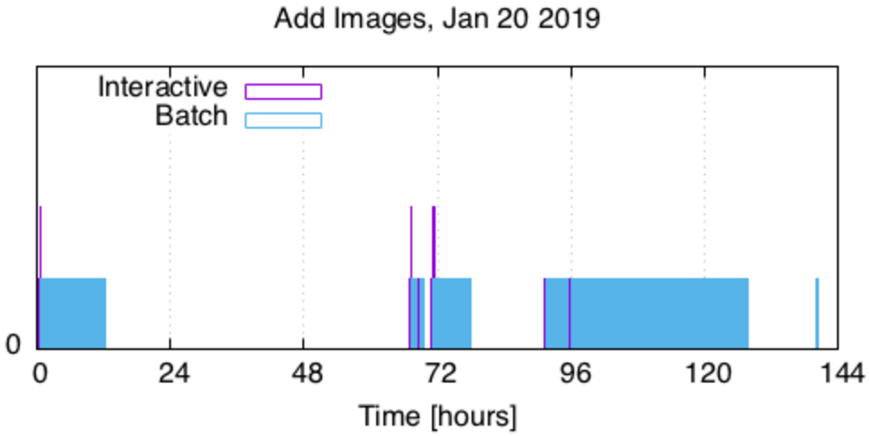

Figure 34 Image Processing Time for Jan 20 images

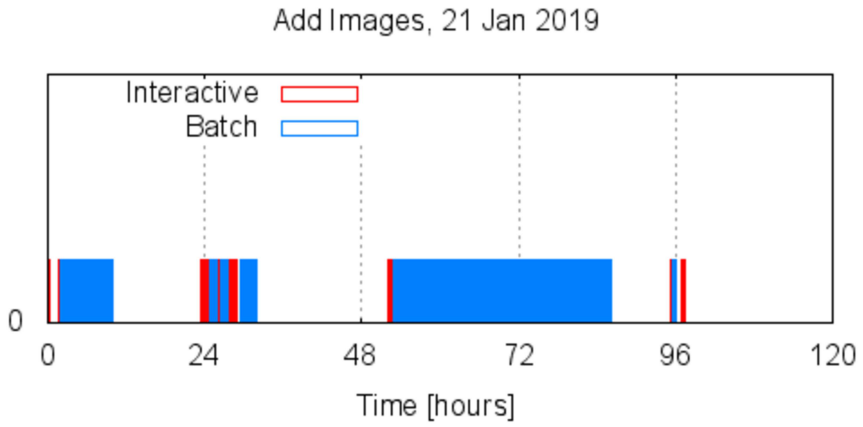

Figure 35 Image Processing Time for Jan 21 images

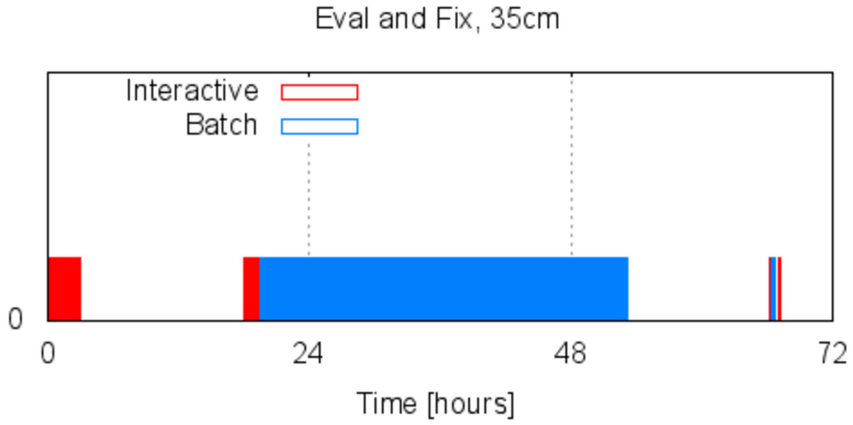

Figure 36 35 cm Evaluation and Fix process time

The test also generated 18 cm maplets that were subsampled to generate the 35cm DTM with higher fidelity. The time, Figures 3.7-3.8, to complete this process took 32 calendar days. This task is not essential to meet the requirement, but was studied to identify what level of effort was needed to reach this processing state.

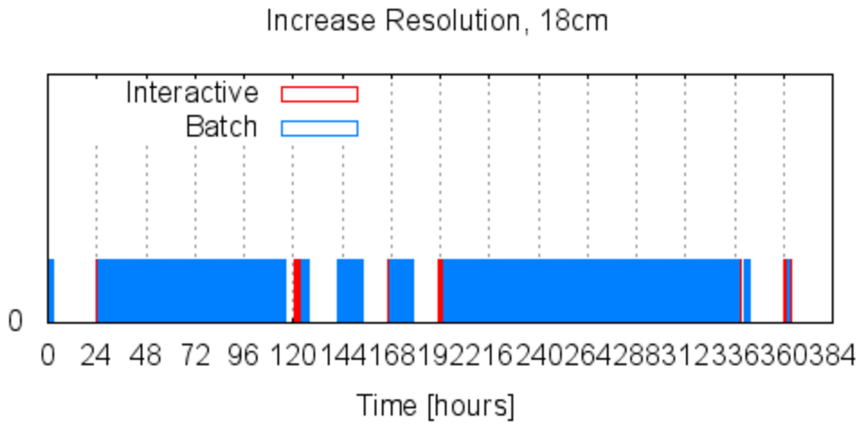

Figure 37 Increase resolution to 18 cm process time

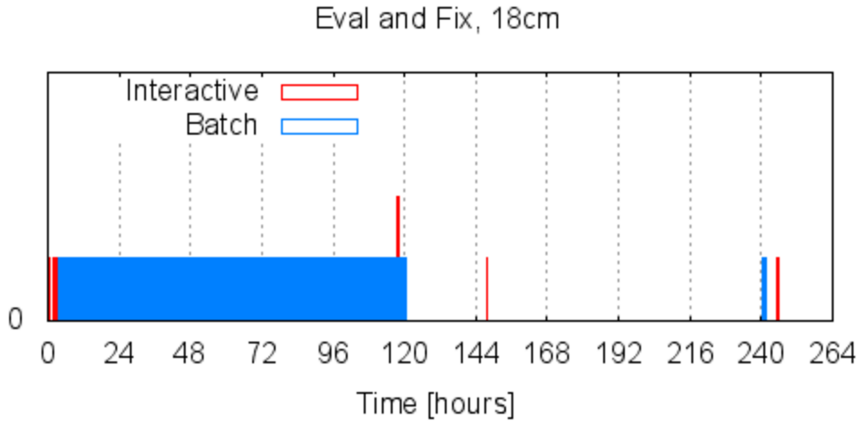

Figure 38 18 cm Evaluation and Fix process time

4. Plan for Re-Testing

There are no plans for any re-testing.

5. Other Findings/Issues and Plan for Resolution

This section, provided by Coralie Jackman, describes a concern about the 3D RMS accuracy evaluation methods used in MLN-F4 and MLN-F5 tests. A description of the methods, extracted from the F4-F5 Test procedure, is described first.

5.1. Description of methods used in F4, F6

The evaluation of the testing products will consist of two parts: incremental tracking of the progress; and a final evaluation of the shape model to identify if the final product matches, within expected tolerances, the "Truth Model".

5.1.1. Incremental Tracking

During the test, the TP will create an end of phase shape model from the progress: Approach (Best), Preliminary Survey, and Detailed Survey @35cm.

The SPOC TL will use the tool CompareOBJPointCloud, from the altimetry working group at APL, to measure the difference between the two models. This will provide the data for statistics and visualizations. To evaluate the 80%, the TL will use the file RESIDUALS.TXT and select the 80% best landmarks (defined as those with the lowest residual values). Using these top 80% landmark, the TL will extract the central vector from the LMK files and generate a point cloud (a vertex of x,y,z in body fixed frame of each landmark). Using this point cloud, he will compare it to the truth model.

The progress of the testing will be presented to GSFC in weekly reports. The TP will be excluded from these conversations and statistics. This will ensure that he/she does not know how well their model is converging to the truth model, nor where there are specific problem areas.

5.1.2. Final Analysis

When the model is sufficiently stable, present the shape model to the TD. The TL will archive the end-state of the SPC directory, and specifically collect the final shape model and landmarks to be used for other tests. The accuracy and precision values will be evaluated according to the FDS topography requirements stated in Table 51.

Table 51 F4 Requirements

Req. ID	Requirement Description	Verification
MRD-678	The Ground System shall, for > 80% of the asteroid surface, produce a set of DTMs at < 0.75 m in ground sample distance (sample resolution). Note: Ground sample distance is defined as the sample spacing of the surface in m/pix.	Full
MRD-680	The Ground System shall, for > 80% of the asteroid surface, produce a set of DTMs with post-fit residual RMS < 0.38 m (1-sigma) for each maplet. Note: Post-fit residual of a maplet is defined as the (pixel, line) difference between predicted model and observed images of the maplet.	Full
MRD-682	The Ground System shall, for > 80% of the asteroid surface, produce a set of DTMs with a 3D RMS accuracy < 1m (1-sigma).	Full
MRD-684	The Ground System shall provide the global 75cm DTM product to FDS within 14 days of downlink of all Preliminary Survey OCAMS and OLA data.	Full

NOTE: 80% percent of the asteroid surface is determined by the following process:

- Run SPC “residuals” to define which landmarks have the lowest residual
- Remove the 20% worse landmarks
- Extract the “Central Vector” of the remaining landmarks to form a “Point Cloud”
  - Simple file of x, y, z vertices
- Compare this point cloud with the truth model
  - It evaluates only those vertices
  - 5cm GSD shape model is evaluated every 2.5m

5.2. Description of concern

Both the ALTWG and FDS teams have identified some fallbacks to the method for evaluating the 3D RMS Accuracy described in the previous section.

First, the landmark vector only defines the origin of the landmark coordinate frame w.r.t. the body-fixed coordinate frame. The topography is described by an array of heights relative to the landmark coordinate frame. The landmark vector magnitude does not necessarily represent the precise height of the model along the vector, because there could be a height defined in the plane above the vector end point.

Second, the method by which the minimum distance is found between the each landmark vector point and the truth plate model is insufficient for assessing the global accuracy of the landmark. If the landmark vector pointed to the bottom of a crater, there is no constraint to guarantee that the nearest point to the truth plate model is also at the bottom of the crater. This method does not compare or correlate the topography between the landmark DTM and the truth model, and as such, cannot assess the 3D RMS accuracy of the landmarks at the resolutions to be evaluated.

While this method did provide a high level metric for convergence of the model, an alternative technique must be employed to assess the accuracy against the requirements. Some alternatives have been discussed between the teams, and preliminary development of evaluation tools has already begun. The current best method for evaluation is to perform a 2D cross correlation of the DTM with a simulated truth image to assess the correlation score and shift between the landmark and the image. Another method is to do a 3D comparison between the truth model and DTM at a higher sampling resolution. The latter required significantly more computation time than the former.

6. Lessons Learned

The following are the lessons learned:

1. SPC uses a suite of scripts to process a large number of small regions in batch. Tools exist to review these automated routines for errors and regions that need additional processing. Any regions that need additionally process take direct human time to review and process, can only be done sequentially, and can take extensive time. For the F6 test, the automated scripts were effective on Shape 4, most of the required time was computer hours
2. The F6 test started with the F4 shape model. The model generated by the F4 test used the Preliminary Survey imaging, which was sufficient for the 35 cm shape model. The addition of 5cm resolution images did not make a significant improvement to the RMS accuracy of the model, although it did greatly improve the cross correlation results.
3. The F6 test was to generate a model at 35cm. In order to ensure an accurate model, we generated topography at a factor of two higher than the ground sample distance of the model we are responsible for, specifically making maplets with a GSD of 18 cm. From test, it shows that tiling at 18 cm did not improve the RMS or accuracy, but improved the cross correlation results.
4. The effort to generate terrain at a higher resolution than the model we were required to build took a significant amount of time. Tiling at 18 cm took 15 calendar days and increased the processing time for the last block (i.e. Eval and Fix 18 cm). It is uncertain if this step is needed to meet mission requirements.