Verification for RSWG MRDs

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1 Summary of Requirement

This plan corresponds to the verification of 4 Radio Science requirements: MRD-133, MRD-134, MRD-135, and MRD-193. The text for these requirements is shown below.

- MRD-133 - OSIRIS-REx shall determine the mass of Bennu to within 0.5%.
- MRD-134 - OSIRIS-REx shall determine the spherical harmonic coefficients of Bennu's gravity field to fourth degree and order.
- MRD-135 - OSIRIS-REx shall determine the center of mass of Bennu to within 1-m.
- MRD-193 - OSIRIS-REx shall determine the YORP effect on Bennu to a precision of $< .01 \times 10^{-3}$ degrees/day/year

These requirements are grouped together because their estimates are produced via the same processing pipeline, namely using the GEODYN II software package. The Radio Science team will process radiometric tracking data, along with altimetry and optical imaging data, in order to determine these parameters. The estimation process returns both the best estimate of the parameters and the accuracy of the estimates.

The formats of the data products associated with these requirements can be found in the RSWG SIS (Ref 3.). Details concerning these data products are found on their respective Data Product Description pages (Ref 4.).

2 Data Products Required

The list of all required data products for RSWG are covered in the ICD.

The RSWG data flow diagram is shown in Fig. **??**. This shows the necessary data for running the REGRES and GEODYN tools for producing the data products necessary to satisfy the MRDs discussed in this document. In particular, RSWG requires from within the SPOC:

- Bennu shape model

- NavCam images
- OLA Level 2 data (particular data product TBD, based on GEODYN)
- SPICE Kernels (CK, SPK, PCK, IK)
- SUMFILES, LMKFILES
- Previous RSWG produced data products

RSWG also requires a number of external data products, most notably DSN radiometric tracking data, as discussed in Section 14.

3 Ability/Availability of the System to Generate Sufficient Observations

RSWG uses radiometric tracking data taken through the HGA and LGA. Our solutions for the present data products are mainly dependent on the Doppler data, which is to have noise at a 1σ level of 0.1 mm/s for data taken at 60 second intervals. Importantly, the LGA is assumed to be able to achieve this data accuracy with a half-angle field-of-view around the boresight of 60°.

The other important data type currently assumed is the NavCam optical navigation images. The noise model is discussed in Ref. 2, but in brief assumes a pointing knowledge uncertainty of 289.48 μrad and a landmark mapping knowledge of 75 cm, both 1σ.

The Radio Science experiment is the main phase for collecting data to meet MRD-134 in particular. This experiment is a 9-day arc of quiescent operations (no maneuvers, no extraneous pointing) which is assumed to have nadir pointing for the first and last day, and sun pointing for the intervening 7 days. The NavCam images are assumed to be taken once every ten minutes when Bennu is in view, and the Doppler tracking data is assumed to be taken every 60 seconds while the Earth is in view of the LGA.

All other phases are assumed to have data taken at the rates in DRM Rev C.

4 Minimum Success Criteria

MRD-133 and MRD-135 will be satisfied after processing tracking data and optical navigation data from Orbital A.

MRD-134 depends on the Radio Science experiment. As discussed in Section 6, the current design does not provide what the RSWG considers adequate data for satisfaction of this requirement.

MRD-193 is mostly dependent on time, and as such will only be satisfied after processing data from the entire proximity operations.

All four MRD data products will have their ultimate solutions delivered after processing data from the entire proximity operations.

5 Dependencies per Mission Phase

As previously stated, the RSWG data and pointing requirements are during the Radio Science experiement in Orbit B. Outside of this, the standard DRM Rev C conops is assumed and considered acceptable.

6 Adequacy of the DRM

DRM Rev C is perfectly adequate for MRDs 133, 135, and 193.

MRD-134 is difficult to meet given the small mass of Bennu. In order to adequately meet this requirement, the RSWG has requested a lower orbit for the Radio Science experiment. Details of the difference between the currently assumed 1 km orbit and the requested lower orbit is discussed in detail in Ref. 2.

7 Data Products per Mission Phase

Data products for MRD-133 and MRD-135 will start to be produced during Preliminary Survey, and will continue throughout the mission. As mentioned above, the requirement should be satisfied after processing Orbital A data.

Similarly, a first data product for MRD-193 will be produced during Approach or Preliminary Survey. This requirement will not be satisfied until after processing data up through TAG rehearsal.

Finally, the data products for MRD-135 will start to be produced during Preliminary Survey, although no updates to the a priori guesses will be available for degrees 3 and 4 until the Radio Science experiment in Orbit B. Updates will continue as appropriate after processing data after the Radio Science experiment throughout the remainder of the mission.

Data will be processed on a continuous bases throughout the mission. Solutions will typically be available within hours to possibly a few days depending on the arc being processed. Data is processed in batches, so typically each every day or every few days new data will be processed to update the previous solutions. This is discussed further in Ref 1.

8 Overview of Processing

Ref. 1 explains the mathematical theory behind the least-squares estimation scheme used to determine the gravity field by the Radio Science Working Group. This process accounts

for the spacecraft and asteroid dynamics, and uses measurement data from the radiometric tracking, altimetry, and optical images.

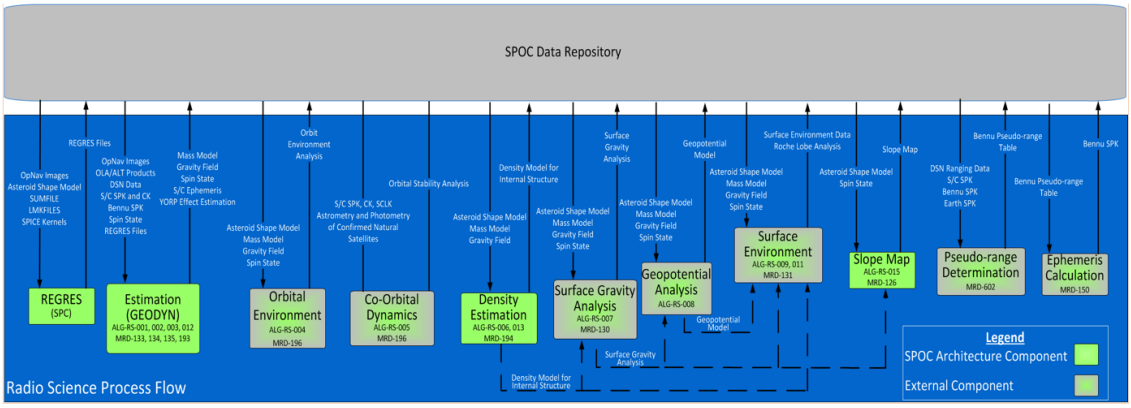

Figure 1: Radio Science data flow diagram.

As previously mentioned, the Radio Science process will use the GEODYN II software, which was created at NASA Goddard Spaceflight Center. The software is distributed by SGT Inc. More information is available at their website: http://terra.sgt-inc.com/geodyn/ This software does require some minor further development, mainly to appropriately ingest the OLA data products. The software is very capable of using the data once it is in the correct format, so this in an input format issue only. This development is currently underway at Goddard, under the direction of Dave Rowlands, a Radio Science team member.

9 Provenance of Algorithms, Software and Techniques

There are many, many references concerning least squares orbit determination and parameter estimation, GEODYN II, and SPC. These can be provided if necessary.

10 Expected/Simulated Data

See Ref. 2 for extensive examples of simulations used to predict the performance of the RS processes for producing the data products to close these requirements. Note that this reference also discusses the improvements in performance if the Radio Science experiment orbit is lowered.

11 Analysis & Verification Methods

The expected accuracy on these data products is analyzed via covariance analysis, which is a standard method for assessing expected estimation accuracy. The results of covariance analyses on these data products is discussed at length in Ref 2.

12 Existing or Potential Liens

The SUMFILES and LMKFILES needed by the REGRES process are not currently tracked as data products by the SPOC, so it is unclear how these data are going to be provided to RSWG. Without these data, RSWG will not be able to process optical navigation images, which are a crucial component of precisely fitting the spacecraft orbit which is necessary to estimate the Bennu gravity field.

For reference as to where the SUMFILES and LMKFILES come from in the SPC process, please see Ref. 5.

13 SPOC Requirements

The RSWG data flow chart was shown in Fig. 1.

The main requirement placed on the SPOC by RSWG is to make available the data necessary for our data processing activities. This data, including the significant external data times, are discussed in detail in the RSWG ICD. Note that this ICD is in progress and we don't have a link to the current copy at this time.

RSWG also needs access to the software to be located at the SPOC, which for these MRDs is the REGRES component of the SPC software, and the GEODYN II software.

14 External Interfaces

The RSWG processes requires data beyond the Level 2 science data typically assumed to reside in the SPOC. Producing these data products is especially dependent on obtaining the radiometric tracking data from the DSN through OSCARx, along with the assorted supporting files. There are also a number of items needed from the FDS/Nav team and/or the MSA, which are to be made available through the FOB. All of these external products need to be made available to the RSWG as discussed in our ICD.

15 References

1. McMahon, Jay, "Background on the Radio Science Estimation Process for OSIRIS-REx," Memo to RSWG, October 2012, available at https://sciwik.lpl.arizona.edu/wiki/pages/P2A6m5D/Geodyn_Algorithm.html

2. McMahon, J. W., Scheeres, D. J., Farnocchia, D., Chesley, S., "The OSIRIS-REx Radio Science Experiment at Bennu," to be published in Space Sciences Reviews, draft available at https://sciwik.lpl.arizona.edu/wiki/pages/U3B5r7/Space_Science_Reviews__Special_Issue.html

3. RSWG SIS, https://sciwik.lpl.arizona.edu/wiki/pages/f6U0c0u7M/SIS.html

4. Data Product Descriptions, https://sciwik.lpl.arizona.edu/wiki/pages/Q4m4w3V/Data_Products_Descriptions.html

5. SPC processing, https://sciwik.lpl.arizona.edu/wiki/pages/31S8n0t5/Algorithm_Descriptions.html