MRD-183a

Data Product Name: Flight System Safety Maps (Global and Site-Specific)

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Requirement MRD-183a: “The Ground System shall produce the following data products on a global scale and for each candidate sample site in support of site selection during the encounter with Bennu: a. Safety Maps”

1. Summary of Requirement:

Safety Maps are required to (1) assess the safety of candidate sites against the limitations of the spacecraft, (2) to ensure additional sampling attempts are possible, and (3) the collected sample can be successfully returned to Earth. The Safety Map will display regions of the surface of Bennu as green that are assessed to provide >99% probability of ensuring the safety of the flight system during sampling. This requirement drives the mission to collect, analyze, and synthesize instrument data to find safe TAG locations, supporting the L1 requirement to acquire and return a sample to Earth. Supporting work determines the quantitative regime for “safe” TAG sites.

2. Data Products Required

The safety map uses data products from the remote sensing instruments, further processed into higher-level data products. The categories for each data product and data product IDs are:

Inputs to Global Safety Maps

Global OBJ (ALT-05): Shape model, for tilt. The shape model is derived from OCAMS imaging and OLA ranging data. The Global OBJ is used to generate the NFT Global Safety Map (SMAP-001), the LIDAR Global Safety Map (SMAP-002), the Safety Global Communications Tilt Map (SMAP-005), the Safety Global Roughness Map (SMAP-006), the Safety Global Thermal Map (SMAP-007), the Safety Global Reflectivity Map (SMAP-008), the Safety Global Plume Map (SMAP-009), and the Safety Global Gravity Uncertainty Map (SMAP-015).

Global Temperature Prediction Map at time of TAG (TA-TBD): Thermal model, for temperature predicts at the local time of TAG. The thermal model is derived from OTES spectral data, and the shape model. The Predicted TAG Global Temperature Map is used to generate the Safety Global Thermal Map (SMAP-007). The format of TA-TBD is ancillary FITS (scalar). (This map is not to be confused with TA-007 and is separate from it.)

Global 1064nm Reflectance Map (IP-7): Reflectance at 1064 nm, for predicted GN&C lidar performance. The reflectance data is scaled from a combination of OCAMS data (for spatial resolution) and OVIRS data (for spectral resolution). The Global 1064nm Reflectance Map is used to generate the Safety Global Reflectivity Map (SMAP-008). The format of IP-7 is a single-band ISIS3 cube.

Global Plume Density Distribution (RD-8): Plume map, for the presence of active plumes or other active dust-generating events. This is a contingency product, generated in the event plumes are visible in approach or detailed-survey imaging. The Global Plume Density Distribution is used to generate the Safety Global Plume Map (SMAP-009). The format of RD-8 is an ESRI shapefile.

Spherical Harmonic Coefficients (RS-006): Gravity model and its uncertainty for predicted NFT performance following the Matchpoint maneuver. The Spherical Harmonic Coefficients gravity model reference radius is used to generate the NFT Global Gravity Uncertainty Map (SMAP-015). The format of RS-006 is ASCII text file.

Global Deliverabilty Map (DMAP-01): The Global Deliverabilty Map is used to generate he NFT Global Safety Map (SMAP-001), the LIDAR Global Safety Map (SMAP-002), the Safety Global Communications Tilt Map (SMAP-005), the Safety Global Roughness Map (SMAP-006), the Safety Global Thermal Map (SMAP-007), the Safety Global Reflectivity Map (SMAP-008), and the Safety Global Plume Map (SMAP-009). The format of DMAP-01 is ancillary FITS.

Inputs to Local Safety Maps:

Local OBJ (ALT-23): Shape model, for tilt. The shape model is derived from OCAMS imaging and OLA ranging data. The Local OBJ is used to generate the NFT Local Safety Map (SMAP-003), the LIDAR Local Safety Map (SMAP-004), the Safety Local Communications Tilt Map (SMAP-010), the Safety Local Thermal Map (SMAP-011), The Safety Local Thermal Approach Map (SMAP-012), the Safety Local Reflectivity Map (SMAP-013), and the Safety Local Plume Map (SMAP-014).

Predicted Local Temperature Map (TA-006): Thermal model, for temperature. The thermal model is derived from OTES spectral data, and the shape model. The Predicted Local Temperature Map is used to generate the Safety Local Thermal Map (SMAP-01) and the Safety Local Thermal Approach Map (SMAP-012). The format of TA-006 is ancillary FITS (scalar).

Local 1064nm Reflectance Map (IP-8): Reflectance at 1064 nm, for predicted GN&C lidar performance. The reflectance data is scaled from a combination of OCAMS data (for spatial resolution) and OVIRS data (for spectral resolution). The Local 1064nm Reflectance Map is used to generate the Safety Local Reflectivity Map (SMAP-013). The format of IP-8 is a single-band ISIS3 cube.

Global Plume Density Distribution Map (RD-8): Plume map, for the presence of active plumes or other active dust-generating events. This is a contingency product, generated in the event plumes are visible in approach or detailed-survey imaging. The Global Plume Density Distribution is used to generate the Safety Local Plume Map (SMAP-014). The format of RD-8 is an ESRI shapefile.

Local Deliverabilty Map (DMAP-02): The Local Deliverabilty Map is used to generate the NFT Local Safety Map (SMAP-003), the LIDAR Local Safety Map (SMAP-004), the Safety Local Communications Tilt Map (SMAP-010), the Safety Local Thermal Map (SMAP-011), The

Safety Local Thermal Approach Map (SMAP-012), the Safety Local Reflectivity Map (SMAP-013), and the Safety Local Plume Map (SMAP-014). The format of DMAP-02 is ancillary FITS.

Each of the five categories and their corresponding MRDs follow. As long as the mission collects data to satisfy the following MRDs, then the corresponding data products to support the safety map are available.

Tilt

MRD-115: OSIRIS-REx shall, for a 3-sigma TAG delivery error ellipse around each of up to 12 candidate sampling sites, produce a topographic map at < 5cm spatial resolution and < 5cm (1-sigma) vertical precision

MRD-678: The Ground System shall, for >80% of the asteroid surface, produce a set of DTMs at <0.75m in ground sample distance (sample resolution)

MRD-687: The Ground System shall, for >80% of the asteroid surface, produce a set of DTMs at <0.35m in ground sample distance (sample resolution)

MRD-126: OSIRIS-REx shall, for > 80% of the asteroid surface, produce a slope-distribution map with a precision of +/- 7.5° in slope, relative to the geoid surface, and spatial resolution < 1m.

MRD-608: OSIRIS-REx shall, for a 3-sigma TAG delivery error ellipse around each of up to 12 candidate sampling sites, produce a tilt-distribution map accurate to +/-7° (1-sigma) in tilt, relative to the sampling plane, and spatial resolution < 32cm. The sampling plane is the plane normal to which the spacecraft negative Z-axis is commanded for TAG, defined by the 2σ TAG delivery error ellipse average normal vector.

Temperature

MRD-155: OSIRIS-REx shall, for > 80% of the asteroid surface, measure the absolute flux of thermally emitted radiation with < 3% accuracy and produce maps of the temperature at seven different local solar times plus the derived thermal inertia at a spatial resolution < 50m.

MRD-411: The Ground System shall produce, within 7 days of final downlink of applicable data, a predicted temperature map of each candidate sampling ellipse for the estimated dates and Bennu times of day for TAG with < 5m spatial resolution and accurate to +/-10K.

Reflectance

MRD-149: The Safety Map WG needs to know the reflectance of the asteroid at 1064nm to ensure that the surface that will be observed with lidar to determine range to surface is within the range of reflectance values in which the lidar is designed to operate. Predictions of the variation in intensity are also important to enabling avoidance of excessively high variations in reflectance that could affect LIDAR ranging performance. A 1064nm Reflectance Map (IP-7 & IP-8) will be generated from OCAMS data (MapCam x-filter at 860nm), scaled by a spatially variable multiplicative factor (1064nm/860nm) to convert from 860nm reflectance to 1064nm reflectance. Alternatively the 1064nm Reflectance Map can be generated by a combination of OVIRS and

OCAMS data, with OCAMS providing the spatial resolution at 860nm and OVIRS providing the relevant OVIRS Spot spectral color ratio at 1064nm/860nm.

Plumes

MRD-143: OSIRIS-REx shall characterize the spectral properties of any detected dust and gas plumes.

Gravity Field

MRD-130: OSIRIS-REx shall, for > 80% of the asteroid surface, map the surface gravity field to within 5x10-6 m/s2 at spatial resolution < 1m.

MRD-134: OSIRIS-REx shall determine the spherical harmonic coefficients of Bennu's gravity field to fourth degree and order.

Deliverability

MRD 183b: Deliverability Map

The Ground System shall produce the following data products on a global scale and for each candidate sample site in support of sire selection during the encounter with Bennu.

a. Safety Maps

b. Deliverability Maps

c. Sampleability Maps

d. Science Value Maps

NFT

MRD-728: The ground system shall produce a catalog of up to 300 NFT features consisting of the following for each feature:

1.) A position defined in Asteroid Center of Figure (ACF) coordinates

2.) A 2-D array of displacement (heights) relative to a reference plane above the asteroid surface to represent the shape.

3.) A 2-D array of relative albedo valued to capture variations in how light reflects off the asteroid surface.

3. Ability/Availability of the System to Generate Sufficient Observations

All of the inputs are derived data products from other groups. As long as the mission collects data to satisfy the MRDs listed in Section 2 (for tilt, temperature, reflectance,gravity field and plumes), then the corresponding data products to support the safety map are available.

4. Minimum Success Criteria

The Safety Map team will produce a map of the relative safety of each region of Bennu for TAG.

The three basic categories for safety are: (i) green, which means that the region is entirely compliant with spacecraft performance requirements; (ii) yellow, which means that the region exceeds performance requirements in one or more categories, but still within spacecraft capabilities; and (iii) red, which means the region exceeds spacecraft performance capabilities.

For nominal conditions, the goal of the safety map is to identify regions of the asteroid that provide a 99% probability of a safe TAG, which would be a region that – when the safety map is combined with the deliverability map – results in only a 1% chance of danger to the spacecraft. If Bennu has regions that are consistent with those limits, the safety map will identify those regions. In the event there are no such regions on the asteroid, the safety map will still identify the “safest” region on the asteroid to TAG.

5. Dependencies per Mission Phase

See the development schedule included as part of the response to "Adequacy of the DRM" below. Both the global and local safety maps depend on the acquisition of science data, and the development of higher-level science-data products, to generate the final safety map.

For the global safety map, the science data and data products are acquired and developed during Approach, Preliminary Survey, Orbital Phase A, and Detailed Survey. The global safety map is generated during Detailed Survey.

The local safety map follows the same two-version delivery – there is an initial version that incorporates all input elements except for the reflectivity map, then a final version that includes the reflectivity map. The initial version is delivered in Orbital Phase B, the final version is delivered during recon.

6. Adequacy of the DRM

Given the DRM achieves the observations to support the completion of the MRDs that are the input products to the safety map, and the working groups have sufficient resources to process the remote sensing data into higher-level products, then the DRM is adequate. The DRM has the proper observations and the processing time scheduled to provide the requisite inputs.

7. Data Products per Mission Phase

Figure 1. illustrates the development timing of the input products to the safety map, and the development of the safety map. Note that this is assuming the Mission Plan Rev A timeline.

Global safety map:

There are two deliveries of the LIDAR global safety map, both during detailed survey (note that the NFT global safety map is a single delivery at the same time as the first LIDAR map). The first incorporates all input science data products except for the 1064 nm reflectivity map, and is intended to provide a "first-look" at the distribution of safe sites on the asteroid. This map utilizes the expectation that Bennu is dark, and will have modest albedo variations across its surface. The second delivery incorporates the 1064 nm reflectivity map, and thus completes a complete assessment of the global safety.

Local safety map:

The local safety map utilizes local equivalents to the global inputs, with the addition of feature availability for NFT map.

The local safety map for Lidar follows the same two-version delivery – there is an initial version that incorporates all input elements except for the reflectivity map, then a final version that includes the reflectivity map. The initial version is delivered in Orbital Phase B, the final version is delivered during recon.

8. Overview of Processing

The high-level processing steps of the safety map are as follows:

Safety map team provides input parameters (approach vector) to the flight dynamics team for the local deliverability map only (see section 14 of this document)

Safety map receives the data products as defined in section 2 of this document

Safety map group uses the delivered data products to develop intermediate maps (tilt, temperature, reflectivity maps)

Safety map group combines the intermediate maps to make a final safety map. This basic process is applicable to both the global and local safety maps. These processing steps are in work.

See algorithm documents listed in the SPOC to Safety Map ICD located on ODOCS:

OSIRIS-REx Ground Systems\9.4 SPOC\9.4.2 Systems Eng\ICDs\WG ICDs\UA-ICD-9.4.4-1017_SPOC to Safety Map ICD_Rev_1.0

The TAGSAM sample arm loads were verified by Monte-Carlo simulation using a spacecraft model to be within limits with margin if the contact dynamics roughness meets the requirements given (presented at CDR; export-controlled analysis not shown here). The gravity uncertainty was also modelled to assure success with margin if the gravity criteria are met. The Plume, communication, NFT feature availability, temperature, and 1064-nm reflectivities are straightforward absolute analyses of conditions that could present a hazard if not met. For example, if the temperature criterion is met, he spacecraft has been verified to operate within normal thermal limits. If the criterion is not met, a more detailed thermal analysis would be required. If the criteria are met at and the simple "do not exceed" criteria are met, then the combined probability of success is at least 99%. A more involved consideration of probabilities is in work to take into account uncertainties in measuring the properties of Bennu (as mentioned in 8.4) that would allow relaxing the safety criterion to 99% probability over a larger area of the surface.

9. Provenance of Algorithms, Software and Techniques

The algorithms are developed for the OSIRIS-REx program: the safety map working group is generating the requirements and algorithms and the SPOC is writing the software to implement the algorithms. See Algorithm Descriptions in related documents.

10. Expected/Simulated Data

We will generate a map that conforms to the map format SIS. Two maps are produced, one with a numerical safety score and one with color coded values. The latter map is color-coded such that specific ranges of numerical values correspond to specific colors (primarily green, yellow and red). An example version, rendered against the shape model, is shown below.

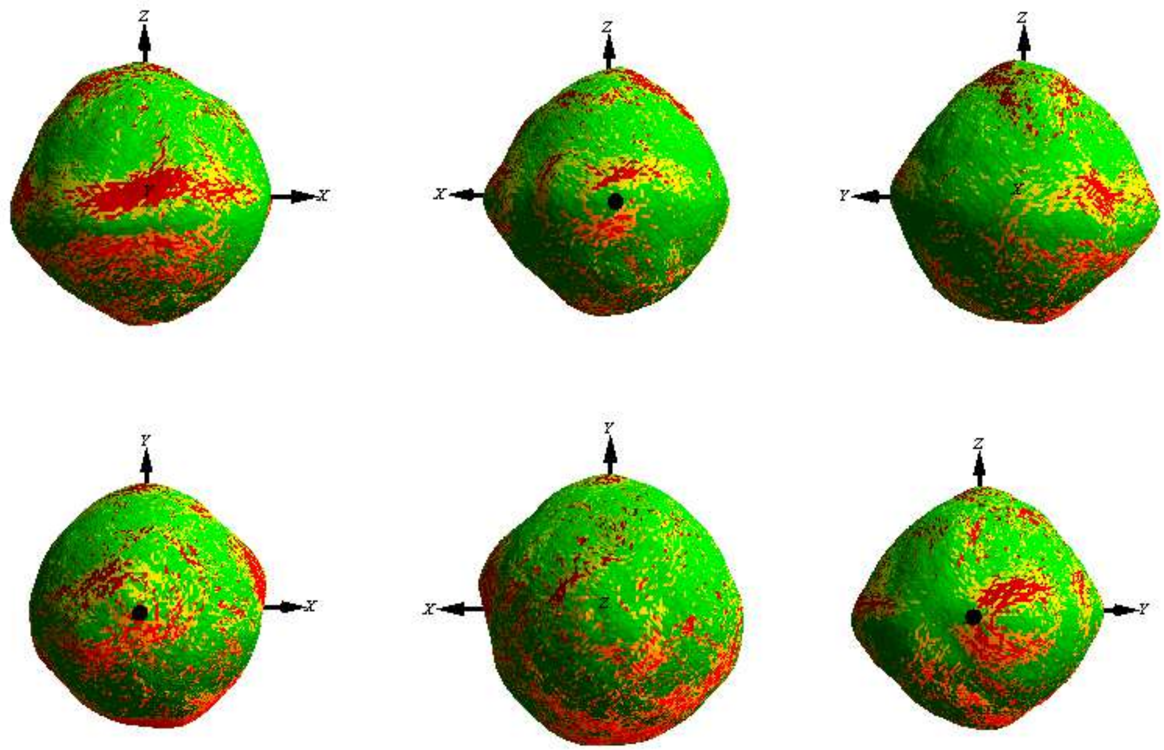

Figure 2: an example of the safety map tied to the global shape model. Green areas are compliant with spacecraft performance requirements (safe), yellow areas are outside performance requirements but within spacecraft capabilities (less safe), red areas exceed spacecraft capabilities.

11. Analysis & Verification Methods

We will use simulated versions of the input data products to generate a version of the safety map. These maps will be tested in the Science testing "SOPIE" process, where the team will make sample Safety Maps using test data provided by the Science Team. The team will work with the SPOC to generate test data that check the correctness of the Safety Map Algorithm implementation.

12. Existing or Potential Liens

Lien-SMWG-1 has closed with the completion of V&V

Lien-SMWG-1 V&V has not been completed

The Safety map team needs to coordinate with the Thermal Analysis Working Group (TAWG) to submit a new data product request. The new product does not require additional remote sensing observations, it is exclusively an adaption of the TAWG thermal model to generate a temperature map that is not currently part of the existing capabilities. The TAWG views the new data product as a straight-forward extension of their current model. This is a global version of TA-06, which is predicted local temperature maps. This is described in section 2.

13. SPOC Requirements

The SPOC will implement the algorithm software. See Algorithm Descriptions and the Safety to SPOC ICD.

The numerical values for the input maps are TBR, but current vales are as follows:

Global

Parameter	Green	Yellow	Red
Angle between antenna boresight and Earth	See Note 1	See Note 1	See Note 1
Tilt (Roughness)	< 14 deg	14-20 deg	> 20 deg
Gravity Uncertainty (altitude below Reference Radius)	< 19 m	19-44 m	> 44 m
Temperature	<= 350 K	See note 2	> 350 K
Reflectance at 1064 nm	0.023-0.069	0.009-0.023 or 0.069-0.115	< 0.009 or > 0.115
Plumes	0	n/a	>= 1

Local

Parameter	Green	Yellow	Red
Tilt	< 14 deg	14-20 deg	> 20 deg
Temperature	<= 350 K	See note 2	> 350 K
Reflectance at 1064 nm	0.023-0.069	0.009-0.023 or 0.069-0.115	< 0.009 or > 0.115
Gravity Uncertainty (ToT error due to gravity dispersions)	< 2s	2-3.75s	>3.75 s
NFT feature availability	> 3 in a trajectory	=3 in a trajectory	< 3 in a trajectory
Plumes	0	n/a	>= 1

Note 1. The acceptable angle between antenna boresite and Earth is dependent on Earth range (and thus TAG date) and 35m vs 70m DSN station. Numerical values for these green/yellow/red will be provided to the SPOC algorithms once these inputs are known. They can be easily obtained from the current Telecom operations analysis tools.

Note 2. Due to the run-time limitations of the Thermal model, it was not feasible or in-scope to run a parameteric analysis to determine the 'breaking point' of the system from a thermal perspective, so no yellow classification is planned (but can be easily added later).

Note 3. Yellow ranges are all currently notional inputs from CPEs. They will be refined in Phase E as the spacecraft in-flight performance is better characterized.

14. External Interfaces

We provide the Flight Dynamics team the approach vector for the local deliverability map, which is derived from the processing of the global safety map.