Origins Spectral Interpretation Resource Identification Security - Regolith Explorer OSIRIS-REx

Thermal Analysis Derived Data Product Software Interface Specification

OSIRIS-REx DOCUMENT

UA-SIS-9.4.4-317, Rev_2.0

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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 Configuration Control Board (CCB) and Configuration Management Lead (CML). Proposed changes shall be submitted to the OSIRIS-REx Project CML, along with supportive material justifying the proposed change.

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DOCUMENT CHANGE LOG

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2.0	Changes to match products as produced		08/15/2022		

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ABBREVIATIONS AND ACRONYMS

Table 1-1: Abbreviations and Acronyms

Phrase/Acronym	Description
Cal/Val	Calibration/Validation
DSN	Deep Space Network
FEDS	Front End Data System
FITS	Flexible Image Transport System
MSA	Mission Support Area
OSIRIS-REx	Origins, Spectral Interpretation, Resource Identification, and Security–Regolith Explorer
OTES	OSIRIS-REx Thermal Emission Spectrometer
OVIRS	OSIRIS-REx Visible and Infrared Spectrometer
PDS	Planetary Data System
SAWG	Spectral Analysis Working Group
SIS	Software Interface Specification
SPOC	Science Processing and Operations Center
SRC	Sample Return Capsule
TAG	Touch-and-Go
TAWG	Thermal Analysis Working Group
UA	University of Arizona

1 SCOPE

1.1 Purpose

The data products described by this Software Interface Specification (SIS) are the OSIRIS-REx Thermal Analysis (TA) derived data products. The OSIRIS--REx Science Processing and Operation Center located at the University of Arizona produces these data products in conjunction with the OSIRIS-REx Science Team Thermal Analysis Working Group (TAWG). The SPOC distributes the data products to both the entire OSIRIS-REx Science Team and the Planetary Data System (PDS).

The purpose of this document is to provide users of the data products with a detailed description of the product and a description of how it was generated, including data sources and destinations. The document is intended to provide enough information to enable users to read and understand the data products. The users for whom this document is intended are the scientists who will analyze the data, including those associated with the project and those in the general planetary science community.

1.2 Applicability

This SIS is applicable to the OSIRIS-REx derived Thermal Analysis Working Group (TAWG)data products, which include global and sample site specific thermal inertia maps and predicted aphelion and perihelion temperature maps. The calibrated input data products from the OSIRIS-REx Thermal Emission Spectrometer (OTES) and the OSIRIS-REx Visual and Infrared Spectrometer (OVIRS) can be found in the OSIRIS-REx PDS Archive located in the Planetary Data System Small Bodies Node environment.

2 APPLICABLE DOCUMENTS

The following documents form a part of this specification to the extent specified herein. In the event of conflict between the documents referenced herein and the contents of this specification, the contents of this specification shall be considered a superseding requirement.

Table 2-1: Applicable Documents

Ref.	Document Number	Title
AD-1		Planetary Data System Standards Reference, Version 1.3.0, September 18, 2014.
AD-2		PDS4 Data Dictionary – Abridged – Version 1.3.0.1, September 24, 2014.
AD-3		PDS4 Information Model Specification, V.1.3.0.1, September 29, 2014.
AD-4	UA-PLN-9.4.4-004	OSIRIS-REx Science Data Management Plan.
AD-5	UA-ICD-9.4.4-101	OSIRIS-REx Science Processing and Operations Center and Planetary Data System Small Bodies Node Interface Control Document
AD-6	UA-ICD-9.4.1-102	OSIRIS-REx Science Processing and Operations Center and Science Team Interface Control Document
AD-7	UA-SIS-9.4.4-306	OSIRIS-REx Visual and Infrared Spectrometer (OVIRS) Uncalibrated / Calibrated Data Product Software Interface Specification
AD-8	UA-SIS-9.4.4-304	OSIRIS-REx Thermal Emission Spectrometer (OTES) Uncalibrated / Calibrated Data Product Software Interface Specification
AD-9	UA- SIS-9.4.4-312	OSIRIS-REx Spectral Processing Derived Data Product
AD-10	UA-SIS-9.4.4-324	OSIRIS-REx Map Format Software Interface Specification

3 RELATIONSHIP WITH OTHER INTERFACES

Changes to the data products described in this SIS affect or are affected by the following software, products or documents:

Table 3-1 Interface Relationships

Name	Type	Owner
SPOC Database Schema	Product	SPOC
OTES Spot Temperatures	Product	SPOC
OTES Calibrated Spectra	Product	SPOC
OVIRS Calibrated Spectra	Product	SPOC
SPOC Archive Packager	Product	SPOC
OSIRIS-REx Data Management Plan	Document	Project

4 DATA PRODUCT CHARCTERISTICS AND ENVIRONMENT

4.1 Observation Overview

The data products described in this SIS are Thermal Analysis data products consisting of thermal inertia and predicted temperature maps. These products are derived from the calibrated observational data of the OTES and OVIRS instruments. For information about the calibrated OTES and OVIRS data please refer to Applicable Documents 7 and 8. OTES and OVIRS derived data products are described in Applicable Document 9. OTES and OVIRS data are processed and/or corrected in several ways to yield temperature, albedo values, and mineral and chemical abundance data for a variety of mineral and chemical species. Data for global data products are acquired during the Detailed Survey mission phase. Data for Site-Specific products are acquired during Orbit-B and Recon mission phases. Descriptions of these mission phases can be found the OSIRIS-REx PDS Archive mission bundle document collection.

Table 4-1 Mission Phase Descriptions

Mission Phase	Sub-Phase	Description
Approach		Approach Phase began on August 17, 2018, when the spacecraft was still about 1.2 million miles (two million km) away from Bennu, and it continued until the spacecraft arrived at the asteroid on December 3, 2018. The primary goals of Approach were to visually locate Bennu for the first time, survey the surrounding area for potential hazards, and collect enough imagery of Bennu to generate a detailed shape model of the asteroid, assign a coordinate system, and understand its spin state.
Preliminary Survey		Preliminary Survey Phase began with the spacecraft's arrival at Bennu on December 3, 2018, and marked the first time that the OSIRIS-REx spacecraft operated around the asteroid. The spacecraft made a total of five passes over the north pole, equator, and south pole at a range of 4.3 miles (7 km). The primary science goals of Preliminary Survey were to estimate Bennu's mass, refine the asteroid's spin state model, and generate a global shape model at a resolution of 75-cm.
Orbit A		In Orbital A Phase, the spacecraft was placed into a gravitationally-bound orbit around Bennu for the first time on Dec. 31, 2018. There were no science requirements for Orbital A, as this phase was designed to provide the mission team with experience navigating in close proximity to a small body. The spacecraft circled Bennu at a distance between 0.99 and 1.3 miles (1.6 and 2.1 km) and travelled around 0.11 mph (5 cm/sec), with each orbit lasting about 61.4 hours.

Detailed Survey	Baseball Diamond	The in-depth study of Bennu began in earnest during Detailed Survey: Baseball Diamond Phase, which kicked off on Feb. 28, 2019. OSIRIS-REx made multiple passes around Bennu to produce the wide range of viewing angles necessary to fully observe the asteroid. The spacecraft also used its OTES spectrometer to map the chemical composition of Bennu's entire surface. Images obtained during this phase were of high enough resolution to produce digital terrain maps and global image mosaics, which were then used to identify proposed sample sites.
	Equatorial Station	During Detailed Survey: Equatorial Stations Phase, the spacecraft executed a series of slews between Bennu's north and south poles while taking observations from seven different stations above the equator. These data were studied to understand the geology of Bennu. The spacecraft also conducted searches for dust and gas plumes.
Orbit B		At the end of Detailed Survey, the spacecraft entered a close orbit – with a radius of 0.6 miles (1 km) – around Bennu to begin Orbital B Phase. The primary science activities for this phase were the global mapping of Bennu, the development of shape modeling based on OLA data, and the execution of a Radio Science experiment. These data were used to evaluate potential sample collection sites.
Orbit C		At the end of Orbital B, the spacecraft transitioned to the slightly higher Orbital C for additional particle ejection observations. During Orbital C, the spacecraft flew approximately 1.3 kilometers above the asteroid's surface.
Recon A (known as Recon in PDS)		During Reconnaissance A phase, the OSIRIS-REx spacecraft performed four flyovers – one for each potential sample collection site. Site Sandpiper was observed first, followed by site Osprey and then site Kingfisher. Observations for this phase concluded with site Nightingale. The spacecraft performed these observations during October 2019 at a distance of approximately 0.6 miles (1 km) from asteroid Bennu's surface.
Orbit R		During Orbital R phase, the OSIRIS-REx spacecraft flew a terminator orbit approximately 0.9 miles (1.4 km) above asteroid Bennu's surface from November 2019 through early January 2020.
Recon B		During Reconnaissance B phase, the OSIRIS-REx spacecraft performed two flyovers – one over the primary sample collection site Nightingale, and another over the backup site Osprey. The spacecraft observed the two sample collection sites from an altitude of approximately 0.4 miles (625 m), which was closer than the previous Reconnaissance A flyovers (approximately 0.6 miles/1 km).
Recon C		During Reconnaissance C phase, the OSIRIS-REx spacecraft performed two flyovers – one of the primary sample collection site Nightingale, and another of the backup site Osprey. The spacecraft observed the two sample collection

		sites from an altitude of approximately 820 ft (250 m), which is closer than the previous Reconnaissance B flyovers (approximately 0.4 miles/625 m).
Sample Collection	Rehearsal	In April 2020, OSIRIS-REx performed its first rehearsal. The spacecraft practiced leaving its orbit, maneuvering to a pre-defined Checkpoint located 410 ft (125 m) above the sample site, and then returned to orbit. In August 2020, the second rehearsal took the spacecraft from orbit through the Checkpoint burn to the Matchpoint burn, where it approached the sampling location before returning to orbit. During each rehearsal, the spacecraft collected and analyzed tracking data and OCAMS and TAGCAMS imagery so that the team could verify the flight system's performance before the actual sample collection maneuver.
	TAG	During the sample collection event, OSIRIS-REx used the TAGSAM (Touch-and-Go-Sample-Acquisition-Mechanism) instrument to collect a sample of regolith from Bennu. TAGSAM is an articulated arm on the spacecraft with a round sampler head at the end. During the Touch-and-Go maneuver (TAG), the sampler head extended toward Bennu, and the momentum of the spacecraft's slow, downward trajectory pushed it against the asteroid's surface for about ten seconds. At contact, nitrogen gas was blown onto the surface to roil up dust and small pebbles, which was then captured in the TAGSAM head.
	Post-Tag Observations	OSIRIS-REx performed a final flyby to observe sample site Nightingale from a distance of approximately 2.4 miles (3.8 kilometers) – capturing its last images of the sample collection site to look for transformations on Bennu's surface after the Oct. 20, 2020, sample collection event.

4.2 Data Product Overview

This SIS describes the derived Thermal Analysis data products produced for the OSIRIS-Rex mission. In general, Thermal Analysis data products are produced as FITS format map files with associated header information. Most products are produced at several stages in the mission, with the first release at a lower fidelity, with subsequent releases at higher spatial resolutions. Specific details for each product can be found in Section 5. The data products described in this SIS are:

1. Global Thermal Inertia Maps – These data products are maps of thermal inertia derived from OTES or OVIRS observational data.
2. Site-Specific Thermal Inertial Maps – These data products are maps of thermal inertia at the four potential sample sites. Custom digital terrain models used in the maps are included with the sample site data products.
3. Global Predicted Temperature Maps – These data products are model results that predict global Bennu surface temperatures at perihelion and aphelion.

4.3 Data Processing

All OSIRIS-REx mission science data processing is performed at the University of Arizona Science Processing and Operations Center (SPOC). OTES and OVIRS science and housekeeping telemetry are received by the SPOC via the Lockheed Martin Mission Support Area (MSA) and the DSN. Telemetry data are reconstructed and stored in the SPOC data repository. Raw data (OREx Level 0) are retrieved from the data repository and fed into the OTES and OVIRS specific data processing pipelines. The pipelines produce calibrated OTES and OVIRS spectral and housekeeping data products.

Generally, OTES spectra are stored in binary table format, OVIRS spectra are stored in FITS file format, and housekeeping in a binary table format. Production rates of spectra vary over the course of the mission based on specific science goals of each mission phase. Spectral Processing uses calibrated OTES and OVIRS data to derive spot temperature, emissivity, mineral and chemical abundance, as well as albedo of the surface of Bennu. Thermal Analysis uses OTES and OVIRS observations as inputs to the asteroid thermophysical model that results in thermal inertia, thermal roughness and predicted temperature values for each spot measurement. Thermal Analysis then uses mapping procedures to make maps of both thermal inertia and predicted temperatures.

4.3.1 Data Processing Level

Table 4-2 shows the OSIRIS-REx data processing levels of all science data products described by this SIS.

Table 4-2. Processing Level

Thermal Analysis Product	NASA/CODMAC Processing Level	OSIRIS-REx Processing Level	Description
Global Thermal Inertia Map	Level -3/ Derived Level 5	L4	Thermal Inertia Map of the surface of Bennu
Site-Specific Thermal Inertia Map	Level -3/ Derived Level 5	L4	Thermal Inertia Maps of potential sample sites
Global Predicted Temperature Map	Level -3/ Derived Level 5	L4	Predicted Temperature Maps of the surface of Bennu

4.3.2 Data Product Generation

As mentioned previously, all OSIRIS-REx science data processing is completed at the SPOC located at the University of Arizona. The decision was made early in the mission lifecycle, that all processing would be centralized to facilitate the relatively quick turn-around needed by the science and operations teams to make tactical decisions about sample site selection. To facilitate the mapping of quantities on to common scale, the OSIRIS-REx mission, a common set of Map

Formats is described in the OSIRIS-REx Map Formats SIS (AD-10). The Thermal Analysis map products are produced in conformance to the Enhanced Shape Model Data Ancillary6 specification (Map Format SIS, section 4.3.2.1).

4.3.2.1 Global and Site-Specific Thermal Inertia Maps

These products measure the average thermal inertia at a spatial scale comparable to the OTES spot size during Detailed Survey for global maps and Reconnaissance phase for site-specific maps. Thermal inertia is a measure of the response of the surface to changes in temperature. Thermal roughness is the irregularity of a surface measured over spatial scales that are comparable to or larger than the diurnal thermal skin depth but smaller than the spatial resolution of the known topography included in the thermal model. Global thermal roughness maps are included with the global thermal inertia products

Global thermal inertia maps are derived from temperatures derived from OTES measurements. The primary observations required are OTES thermal flux observations at several times of day of the surface of Bennu. These observations were collected during Detailed Survey, when the spacecraft observed Bennu for an entire rotation from each of 7 stations: 8:40pm, 6pm, 3pm, 12:30pm, 10am, 6am, 3:20am. Spacecraft and asteroid position were also collected for input into the data processing environment. Site-specific thermal inertia maps are derived from OTES observations taken during Reconnaissance flyovers of potential sample sites. The primary observations required are OTES thermal flux observations. Spacecraft and asteroid position are also required to calculate the thermal inertia for these observations. See Rozitis et al., 2020 (DOI: 10.1126/sciadv.abc3699) and Rozitis et al., 2022 (DOI:10.1029/2021JE007153 for details of the thermal inertia calculations and the thermal physical model.

Input data, including OTES spectra, were read from the SPOC database. The asteroid thermophysical model was run at the location of each OTES measurement to find the thermal inertia that best-fits the diurnal temperature curve at that location. The mission mapping software was used to bin and average the derived thermal inertia into appropriate format for the maps.

Uncertainties of the derived thermal inertia and roughness values were quantified through a Monte Carlo method, using the bootstrap method described in Press et al. (1992; *Numerical Recipes in C,* pp. 656-706). The bootstrap method estimates the uncertainties by performing multiple fits of different randomly chosen combinations of independent observations. Each different fit gives a slightly different set of best-fit properties, and the resultant property distributions are characteristic of the model uncertainties. For the analysis of the OTES and OVIRS data, this translated to fitting different randomly chosen combinations of the overlapping spots. For any given location on Bennu, we produced 1000 different spot combinations from all the spots that projected onto that location and found the best-fit thermal inertia and roughness for each spot combination. After the best-fit thermal inertia and roughness were found for each spot combination, we calculated their average value and SD to characterize the overall fit uncertainties. See Rozitis et al., 2020 (DOI: 10.1126/sciadv.abc3699) for more detail.

4.3.2.2 Global Predicted Temperature Maps

Global predicted temperature maps were computed from both OTES and OVIRS thermal inertia maps. Diurnal maximum and minimum predicted temperature maps are provided at both aphelion and perihelion in order to bound the temperatures experienced by the surface of Bennu. Temperature predictions were calculated using the asteroid thermophysical model with the thermal inertia and thermal roughness maps as inputs. The global shape model, Bennu ephemeris, and Bennu spin state are also required.

Predicted temperature maps are stored as a map of Bennu, at the desired spatial resolution (an input variable, not to be coarser than 5m). The file will include input parameters and thermal model version number.

Uncertainties in predicted temperature are derived from the same bootstrap Monte Carlo analysis described in section 4.3.2.1. Different randomly chosen combinations of OTES/OVIRS spots are analyzed to give different best-fit thermal inertia and roughness values. Each best-fit thermal inertia and roughness value is used to predict the temperatures, which are then averaged, and the standard deviation gives the uncertainty. The OTES instrument precision is <1 K, and predicted temperature uncertainties are computed from averaging 10 to 50 spots (depending on the coverage of the given shape model facet), resulting in small uncertainties. The reported statistical uncertainties in the predicted temperature assume the shape model is perfect. Examination of different shape models suggests an additional ~3 K (1-sigma) uncertainty from the shape.

4.3.3 Data Flow

Thermal Analysis data products were derived from input data products stored in the SPOC data repository. Input products such as the OTES spectra are retrieved from the SPOC data repository and fed into the Thermal Analysis data processing algorithms. Thermal Analysis data products are produced and returned to the SPOC data repository for storage and retrieval by the rest of the OSIRIS-REx Science Team. Specifics of each data processing algorithm are discussed in Section 5.

It is possible that more than one version of the Thermal Analysis data products may be produced, however derived data products will be delivered as the best and final products. Updated versions of the products are not expected.

4.3.4 Labeling and Identification

OSIRIS--REx science data products are named according to the OSIRIS--REx Naming Conventions Document (UA-HBK-9.4.4-905). The following paragraphs are excerpts of this document that describe how Thermal Analysis files are named. The generalized file naming convention is:

Coverage Type(1) + "_" + Resolution(6) + "_" + SDP Area + "_" + Process Type + "_" + Description(10) + "_ " + "v" + Version#(3) + "." + PDS Type

Coverage Type is either G for Global or L for Local.

Resolution is the spatial resolution in the 5 character format of NNNNun, where NNN = number, and un = units of km, cm, or mm. Special case is where Bennu is a point source where the resolution field will be 000PS.

File Creation Date is in the format YYYYMMDD"T"HHMMSS"S"ssss"Z"

SDP_Area is TA, for Thermal Analysis

Process_Type is one of :

THERMIN – Thermal Inertia

THERMROUGH – Thermal Roughness

MINPERITEMP – Minimum perihelion temperature

MAXPERITEMP – Maximum perihelion temperature

MINAPTEMP – Minimum aphelion temperature

MAXAPTEMP – Maximum aphelion temperature

Description field is free form. In the thermal products the description may have the sample site identified, or the mission phase from which the input were acquired.

PDS_Type is .fits as all files are .fits format files.

There is one exception to the file naming conventions in the Thermal Analysis bundle. In the data_thermal_maps collection site_specific_thermal_inertia maps directory, there are four .obj files that describe the shape of the surface at each sample site. These shape model files were custom created for the site specific thermal inertia maps based on project created shape model files that are archived in the Altimetry bundle. The .obj files included in the site_specific_thermal_inertia directory are names as follows:

(site_name)_Rozitis22.obj

Where site_name is one of nightingale, osprey, kingfisher, or sandpiper, and Rozitis22 refers to the publication:

Rozitis, B., Ryan, A. J., Emery, J. P., Nolan, M. C., Green, S. F., Christensen, P. R., et al. (2022). High-resolution thermophysical analysis of the OSIRIS-REx sample site and three other regions of interest on Bennu. Journal of Geophysical Research: Planets, 127, e2021JE007153. https://doi.org/10.1029/2021JE007153

4.4 Standards Used in Generating Data Products

4.4.1 PDS Standards

All data products described in this SIS conform to PDS4 standards as described in the PDS Standards document noted in the Applicable Documents section of this SIS. Prior to public release, all data products will have passed both a data product format PDS peer review and a pre-release PDS peer review to ensure compliance with applicable standards.

4.4.2 Time Standards

Time Standards used by the OSIRIS-REx mission conform to PDS time standards. The spacecraft clock (SCLK) reference is 1/1/2000 12:00:00 UTC, with a minimum range date from 1/1/2010 to 1/1/2030. Onboard time tagging is the standard 32-bit seconds and 16-bit subseconds. All OSIRIS-REx data products contain both the spacecraft clock time (SCLK) of data acquisition and a conversion to UTC to facilitate comparison of data products.

4.4.3 Coordinate System

All coordinate systems used by the OSIRIS-REx mission conform to IAU standards. A complete discussion of the coordinate systems can be found in the document "Bennu Coordinate System Description" located in the orex.mission document collection. The Bennu coordinate system is deployed in the mission through the creation and used of SPICE kernels which are used in the creation of mission approved shape models. These shape models are in turn used to create Ancillary FITS map file templates based on the facet construction of the approved shape model. Science Working groups use the approved Ancillary map file templates to enumerate the data values for each facet of the identified shape model .OBJ file.

4.4.4 Data Storage Conventions

All data products produced by the Thermal Analysis Working group are formatted as .fits files. All .fits files conform to the FITS Standard, version 4.0, July 22, 2016.

4.4.5 Data Validation

The SPOC has a comprehensive Verification and Validation Plan for all software used at or developed by the SPOC. All software is configuration controlled and any changes made follow the SPOC Configuration Control Plan, which includes substantive testing of changes.

In addition to software types of verification and validation, each OSIRIS-REx data product has been peer reviewed for both PDS data format acceptability and scientific usefulness. No changes are expected to data formats after peer review. The SPOC Configuration Control Plan governs any changes, should they be needed.

Product validation of the thermal inertia maps will assume that the OTES temperature data used as inputs to the maps have already been validated. The map contents will be validated by inspection for erroneous data values or obvious positioning errors indicated by non-physical thermal inertia variations. If the maps are valid, then the thermal inertias should be a smoothly varying function of latitude and longitude. The maps will also be examined by inspection to observe any data gores, which could indicate missing data or unexpected exclusion of data through incorrect or overly limiting constraints.

Product validation of the temperature maps will assume that the OTES temperature data used as inputs to the maps have already been validated. The map contents will be validated by inspection for erroneous data values or obvious positioning errors indicated by non-physical temperature variations. If the maps are valid, then the temperatures should be a smoothly varying function of latitude and longitude. The maps will also be examined by inspection to observe any data gores, which could indicate missing data or unexpected exclusion of data through incorrect or overly limiting constraints.

5 DETAILED DATA PRODUCT SPECIFICATION

The following sections provide detailed data product specifications for each Thermal Analysis derived data product. These specifications will provide sufficient detail, so that data product users can read and interpret the products.

5.1 Data Product Structure and Organization

The OSIRIS-REx archive is organized into bundles for each science instrument (OCAMS, OTES, OVIRS, OLA, TAGCAMS, REXIS), SPICE, and each type of higher-order data product. The higher order data product bundles, like the Thermal Analysis bundle contain a data collection grouped by map type and a document collection to provide the appropriate ancillary information to properly interpret and use these data products.

The bundle structure is as follows:

thermal.orex

- document
- data_thermal_maps
  - global_thermal_inertia_maps
  - site_specific_thermal_inertia_maps
  - predicted_temperature_maps

Bundle logical identifiers (LID) are formulated following PDS4 requirements as:

urn:nasa:pds:bundle:collection:product

The specific Thermal Analysis LIDS are in the format:

urn:nasa:pds:orex.thermal:data_thermal_maps:(product filename)

urn:nasa:pds:orex.thermal:document:(product filename)

5.2 Data Format Descriptions

5.2.1 Global Thermal Inertia Maps

The global thermal inertia and thermal roughness PDS4 data product is a set of three files: the Ancillary map FITS file, the text logfile, and the xml PDS4 label.

The global thermal inertia and thermal roughness FITS files are formatted in accordance with the OSIRIS-REx Map Formats SIS Enhanced Shape Model Data Ancillary 6 specification, which specifies one data value and standard deviation per shape model facet. Ancillary 6 products are FITs files, with two extensions. The first extension is a zero-length image, and the second is a binary table that contains the map value information for each facet of the shape model. The primary and secondary FITs headers and the PDS4 labels contain identification information as described in the OSIRIS-REx Map Formats SIS Section 5.2.1.2 Ancillary FITS file. Specifically, keywords are defined in Table 3. Global Ancillary File. FITS keywords are translated into the PDS4 .XML label and are generally found in the <Mission_Area> of the PDS4 label. One exception of note to the standard Ancillary 6 primary FITS header is that the Thermal specific FITS keywords are found before the spatial information rather than below.

In addition to the meta data captured in the FITS headers, the thermal inertia and thermal roughness data products PDS4 labels contain a pointer to a supplemental text file that contains the original data processing information as produced by the Asteroid Thermophysical Model. Some of the information contained in this text file is redundant with information in the PDS4 label, however more context is provided in the supplemental text file.

5.2.2 Site Specific Thermal Inertia Maps

The site-specific thermal inertia map products are formatted in accordance with the OSIRIS-REx Map Formats SIS Section 5.2.1.2 Ancillary FITS file, Table 4 Site-Specific Ancillary File. These products are formatted as FITs files, with two extensions. The first extension is a zero-length image, and the second is a binary table that contains the map value information for each facet of the map area. The primary and secondary FITs headers and the PDS4 labels contain identification information as described in the OSIRIS-REx Map Formats SIS Section 5.2.1.2 Ancillary FITS file. FITS keywords are translated into the PDS4 .XML label and are generally found in the <Mission_Area> of the PDS4 label.

In addition to the meta data captured in the FITS headers, the thermal inertia data products PDS4 labels contain a pointer to a supplemental text file that contains the original data processing information as produced by the Asteroid Thermophysical Model. Some of the information contained in this text file is redundant with information in the PDS4 label, however more context is provided in the supplemental text file.

In addition to the site specific thermal inertia products, customized .OBJ shape model files are included with the thermal inertia maps. The site specific thermal inertia map files correspond to the appropriate site's .OBJ file. The .OBJ file is formatted according to Section 5.2.1.1 OBJ format in the OSIRIS-REx Map Formats SIS.

5.2.3 Global Predicted Temperature Maps

The global predicted temperature map products are formatted in accordance with the OSIRIS-REx Map Formats SIS Section 5.2.1.2 Ancillary FITS file, Table 3. These products are formatted as FITs files, with two extensions. The first extension is a zero-length image, and the second is a binary table that contains the map value information for each facet of the map area. The primary and secondary FITs headers and the PDS4 labels contain identification information as described in the OSIRIS-REx Map Formats SIS Section 5.2.1.2 Ancillary FITS file. FITS keywords are translated into the PDS4 .XML label and are generally found in the <Mission_Area> of the PDS4 label.

In addition to the meta data captured in the FITS headers, the temperature data products PDS4 labels contain a pointer to a supplemental text file that contains the original data processing information as produced by the Asteroid Thermophysical Model. Some of the information contained in this text file is redundant with information in the PDS4 label, however more context is provided in the supplemental text file.

5.3 Label and Header Descriptions

Each Thermal Analysis data product has an associated detached PDS4 compliant XML label. This label contains enough information for a user to understand and interpret the data product and the circumstances of data collection.

All of the Thermal Analysis data products are produced as .fits files with associated header information. The headers are keyword = value in format. Header information includes mission, timing, geometry and input file specific information. The information contained in the FITS header is duplicated where appropriate in the detached PDS XML label.

The Thermal Analysis specific FITS keywords and their relationship to the PDS4 label are described in Table 5-1. Thermal Analysis Specific Header Items.

Table 5-1. Thermal Analysis Specific Header Items

FITS Header Keyword	Definition	PDS4 Label XPath
INSTRUME	Instrument used to collect the observations that are mapped.	<Observation_Area><Observing_System><Observing_System_Component>
UNITS	Thermal Analysis specific keyword that gives the physical units of the map product. Units will either be temperature kelvin (K) or SI Thermal Inertia Units (J m^-2 K^-1 s^-1/2)	<File_Area_Observational><Table_Binary><Record_Binary><Field_Binary><units>
DATE-OBS	The observation date time of the first observation input into the Thermophysical	<orex:Mission_Area><orex:Thermal_Specific_Attributes><model_start_time>

	Model. This time is used for model initialization only.	
SUBPHASE	OSIRIS-REx team colloquial mission subphase name. This keyword is translated to official mission phase names in the PDS4 label.	<orex:Mission_Information><orex:mission_phase_name>
LOCTIME	The LOCTIME keyword indicates if a local time restriction was used in the thermal modeling	<Mission_Area><orex:Thermal_Specific_Attributes><orex:loc_time_restriction>
ALGRTHM	Name of algorithm used for mapping. Thermal maps are created using an averaging algorithm for each map facet.	<Mission_Area><orex:Thermal_Specific_Attributes><orex:mapping_algorithm>

6 APPLICABLE SOFTWARE

6.1 Utility Programs

At the current time, the OSIRIS-REx project has no plans to release any mission specific utility programs.

6.2 Applicable PDS Software Tools

The PDS supplies a number of software tools that can be used in conjunction with PDS data products. Please refer to the PDS4 software website (http://pds.nasa.gov/pds4/software/index.shtml) for additional information on these tools.

6.3 Software Distribution and Update Procedures

As the OSIRIS-REx project will not be providing software, this section is not applicable.