MRD 156- Asteroid Thermal Model

Data Product Overview

Executive Description

The asteroid thermal model will enable the team to ingest measurements of the surface and calculate thermal inertia and temperature imbalance (for Yarkosvsky experiment) and predict temperatures for future mission phases.

Overview

The asteroid thermal model will consist of software and any supporting files required to 1) predict temperatures for different mission phases, 2) determine thermal inertia from data returned by the spacecraft, and 3) investigate the Yarkovksy and YORP effects. Currently, the TAWG envisions three components to the thermal model.

1. A finite-difference numerical model to calculate temperatures at (and below) the surface of Bennu, subject to the boundary conditions of energy balance at the surface and constant temperature (or zero flux) at depth. This model will be used before arrival at Bennu to produce a multi-dimensional look-up table (dimensions and parameters TBD).
2. The multi-dimensional look-up table. This is a table with dimensions corresponding to parameters that affect the temperature solutions. It is sort of a "grid calculation" of all possible combinations of the parameters. Each parameter (dimension) varies within its own individual range of relevance. The TAWG is still working out the parameters (dimensions of lookup table) and the number of nodes for each dimension. It will likely include at least the following:
    - Latitude (-90 to 90)
    - Local Time (0 to 24 hrs)
    - Thermal Inertia (0 to 2500)
    - Bond Albedo (range TBD; perhaps 0.005 to 0.10)
    - Orbital position (0 to 360 deg in true anomaly)
    - Local surface slope/tilt (TBD; perhaps 0 to 30 degrees)
    - Roughness (TBD; perhaps 0 to 50 deg, RMS)
    - Azimuth of observation (0 to 360 degrees)
3. Software to interpolate the multi-dimensional look-up table to determine the necessary parameters (i.e., thermal inertia, temperature, radiation forces) from spacecraft measurements. This software will accept OTES data (fluxes for Approach, temperatures for other mission phases) and other inputs (e.g., pointing information, albedo and tilt maps; see DPDs for thermal inertia products) and will interpolate the look-up table to find the best-fit thermal inertia for those data and inputs.

The thermal model itself, including all three components listed above, will be in place before arrival at Bennu. It is not anticipated that any adjustments will be made to the model itself after arrival. The only exception would be if some parameter were found to vary outside of one of the

predetermined ranges. However, the goal is to use wide enough ranges to ensure this does not happen.

The thermal model will be used in Approach phase to determine rotationally resolved thermal inertias from OTES flux measurements and to produce temperature predictions for upcoming phases using those thermal inertias.

It will be used in Detailed Survey to determine global thermal inertias from OTES spot temperatures at the 7 time-of-day stations and to produce temperature predictions for upcoming phases using those thermal inertias.

It will also be used in Reconnaissance to determine site-specific thermal inertias from the OTES spot temperature measurements and to produce temperature predictions for sampling using those thermal inertias.

It will also be used for the Yarkovsky investigation and long-term science.

Data Product Structure and Organization

The product in this case is the model itself.

The first component, the finite-difference numerical model, will be a program of a few thousand lines of code, likely C (or C++).

The second component, the look-up table, will be a binary file consisting of floating point values corresponding to the dimensions of the table and number of nodes for each dimension. It will likely be 10s to 100s of MB in size

The third component, the interpolation software, will be a program of at most a few hundred lines of code, likely written in C (or C++) or DaVinci.

Data Format Descriptions

Finite-difference numerical model

Header data (metadata) to be included:

- Version number
- Change history log
- Example calling sequence
- Description of possible input parameters
- Description of output

Detailed Description of Data Format

- ASCII file of code (~few thousand lines)

Look-up Table
Header data (metadata) do be included:

- Number of dimensions
- Parameter description for each dimension
- Number and values of nodes for each dimension
- Version number
- Version number of finite-difference model used to create look-up table

Detailed Description of Data Format

- Data type - floating point array (7 or more dimensions)
- Field 1 - Surface temperatures (0 to ~500) for grid point of parameters, floating point, precision of 0.1

Interpolation Software
Header data (metadata) to be included:

- Version number
- Change history log
- Example calling sequence
- Description of possible inputs
- Description of output

Detailed Description of Data Format

- ASCII file of code (< few hundred lines of code)

Data Product Generation

The TAWG will develop finite-difference numerical model and interpolation software during Phase C/D. The TAWG also plans to populate the look-up table in Phase C/D. However, depending on dimensions and number of nodes, population of the look-up table may extend into Phase E.

Co-I Emery has been assigned to this product

Multiple versions of the product are not expected. The software and look-up table should be frozen before arrival; these are expected to be robust for all phases of the mission. However, if updates are required, detailed change longs will be maintained.

Data Product Validation

Verification of the algorithm against previously developed algorithms and expected results will come from application to existing data sets. These data sets may include telescopic observations of asteroids, spacecraft observations of asteroids (e.g., Dawn at Vesta) and comet nuclei (e.g., Deep Impact at Tempel 1) and possibly the Moon (LRO/Diviner) and Mercury (MESSENGER).

The algorithm flow will also be tested by blind tests, applying the algorithm to modeled data using our best understanding (shape, etc) of Bennu.

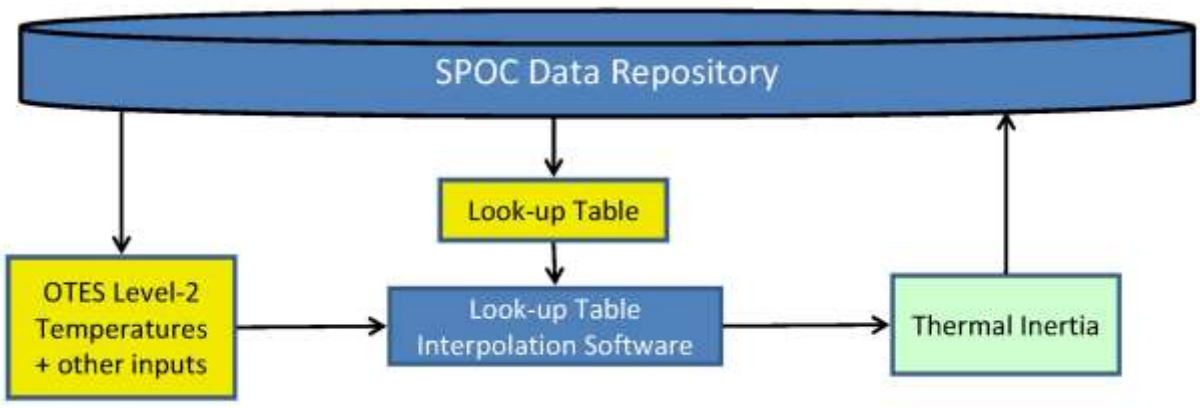
Data Flow

The product in this case is the thermal model itself. The flow for development of the different components is as follows:

1. Finite-difference numerical model. This will be developed based on existing similar models. Details of the algorithm are given in the Thermal Model Algorithm Description. This model will take input parameters (corresponding to grid points in the look-up table) and compute equilibrium surface temperature.
2. Look-up table. Will be populated with temperatures calculated using the finite-difference numerical model for each grid point in the look-up table.
3. Interpolation software. Can be developed in parallel with other components. Will read the look-up table and interpolate among the grid points.

I'm not sure that a data flow diagram for the production of this product is useful, since the product is the model itself, which is intended to be frozen before arrival. The actual algorithm is described in the Thermal Model Algorithm Descriptions.

A general data flow diagram for the use of the model at the asteroid is given here to illustrate the planned use of the model at Bennu, which will only involve components 2 and 3.



Standards Used to Generate Data Product

To be worked out with the SPOC.

Data Product Storage

The main model will be a program of a few thousand lines of code. A multi-dimensional look-up table will likely be produced before arriving at the asteroid in order to speed up interpretations during operations at the asteroid. This lookup table will likely be on the order of a few 10s or 100s of MB.

Observation Requirements

There are no observation requirements on the thermal model itself. The model is just the software that is used to determine thermal inertia from the temperature measurements. The observation requirements are set by the thermal inertia and temperature products.