Thermal Model- Lookup Table Development

Overview

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).

History

Draft - 17 Aug 2013

Baseline - 30 Nov 2013

Algorithm Description

1. The finite difference technique for 1-D heat diffusion (e.g., Crank-Nicholson) breaks the diffusion equation down into finite steps in both time and depth. Initial temperatures for all depths at the start time (t0) are set (wise choices here can significantly improve efficiency) by the user or code. Relevant boundary conditions (typically zero heat flux at depth and energy balance at the surface) are used to calculate the top and bottom temperatures for each new time step. Incrementing from one timestep to the next, for all depth nodes, can then be written as a set of linear equations and efficiently solved with matrix techniques (e.g., LU decomposition). The temperatures at the end of a single time period over which boundary conditions are varying (e.g., rotation period) are generally not yet converged. Therefore, these temperatures are used as initial temperatures in another iteration. This iteration process continues until the temperatures (at all depths) converge so that they change less than a user defined limit (e.g., fractional change of 1e-4). This process is carried out independently for each surface facet, so is readily parallelizable if desired.
2. Initialize model run with parameters for which to calculate model temperatures
    - The TAWG is still working out the parameters (dimension 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. Initialize model parameters (e.g., time step, depth step, physical quantities)
4. Estimate initial temperature profile
    - One option is to estimate the average diurnal temperature and use that. The temperatures at depth should be very close to this value
    - If the model has been run previously for similar parameters for the same object, it might be reasonable to use those temperatures
5. Begin iteration over time (these steps are also repeated for each surface facet)
    - Compute matrix coefficients from temperatures at previous time step

        - If physical parameters (i.e., density, thermal conductivity, head capacity) are constant (i.e., not depth or temperature dependent), this step should occur outside of the loop to reduce the number of computations.
    - Compute surface and deep temperatures for current timestep from boundary conditions and temperatures from the previous time step
    - Matrix solution to compute temperatures at all depths at current time step
    - At the end of each period of variation of boundary conditions (e.g., rotation period for diurnal temperatures) check for convergence of temperatures. If converged, leave iteration. If not converged, iterate again for another period.
6. When temperatures have converged, write the model temperatures to the multi-dimensional Thermal Model Lookup Table.

Parameters

Input

- User will define the dimensions to run the model over and the nodes for each dimension, as outlined above.

Output

- Multi-dimensional lookup table

Keywords

TBD. Keywords may be used to turn on or off various parameters or settings.

References

Finite difference techniques have been used frequently for modeling temperatures of surfaces of planetary bodies. A few relevant references include:

- Emery, J. P., D. P. Cruikshank, and J. Van Cleve (2006) Thermal emission spectroscopy (5.2 - 38 µm) of three Trojan asteroids with the Spitzer Space Telescope: Detection of fine-grained silicates, Icarus, 182, 496-512.
- Kieffer, H. H. (2012) Thermal model for analysis of Mars infrared mapping, JGR-in press. (Despite the title of the paper, this is a generalized thermal model applicable to airless bod-ies as well as Mars.)
- Delbó, M. and Tanga (2009) Thermal inertia of main belt asteroids smaller than 100 km from IRAS data. Planetary and Space Science, 57, 259.
- Rozitis, B. and Green, S.F., "Directional characteristics of thermal-infrared beaming from atmosphereless planetary surfaces - A new thermophysical model", Mon. Not. R. Astr. Soc., 415, 2042-2062, 2011.
- Vasavada, A.R., Paige, D.A., Wood, S.E. 1999. Near-Surface Temperatures on Mercury and the Moon and the Stability of Polar Ice Deposits. Icarus 141, 179-193.

The numerical technique itself is described in detail in Numerical Recipes.