TEMPEST

Thermophysical Equilibrium Model for Planetary Environment Surface Temperatures

An Open-Source Python-Based Model for Predicting Temperature Variations on Airless Planetary Bodies

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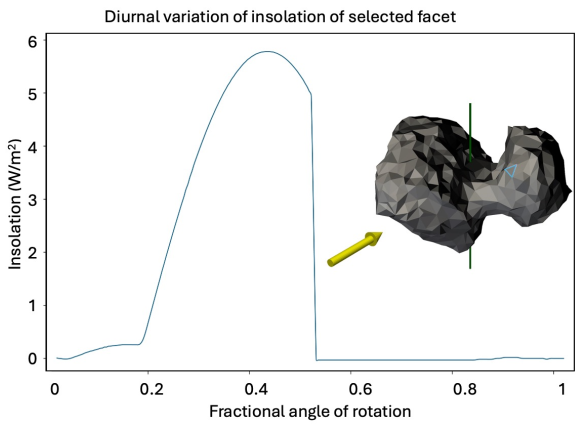
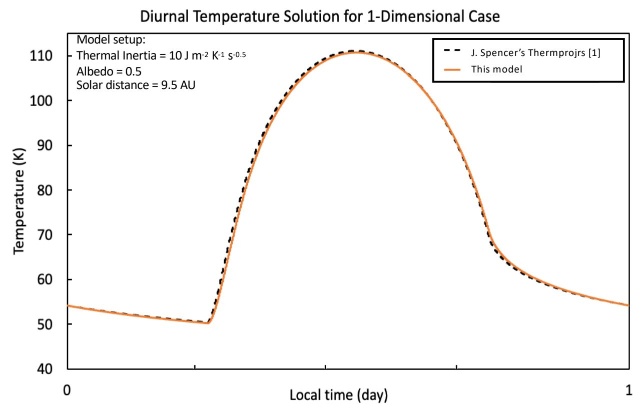
ABSTRACT: Understanding the thermal properties of comets, asteroids, and icy moons is crucial for advancing our knowledge of their composition and evolution. With high-quality shape models and close-up thermal observations of asteroids, comets, and moons from missions like ESA's Rosetta and Juice, as well as NASA's OSIRIS-REx and Europa Clipper, there is an increasing need for high-resolution thermophysical models that accurately consider the complex topographies of these bodies.

Presented here is a newly developed Python model that predicts diurnal temperature variations on airless bodies in three dimensions, factoring in their morphologies. This model significantly improves simulation accuracy by incorporating shadowing effects. The results are consistent with established models such as the one-dimensional thermal conduction model, thermprojrs of Spencer et al. [1], and the three-dimensional surface energy balance model by Guilbert-Lepoutre and Jewitt [2].

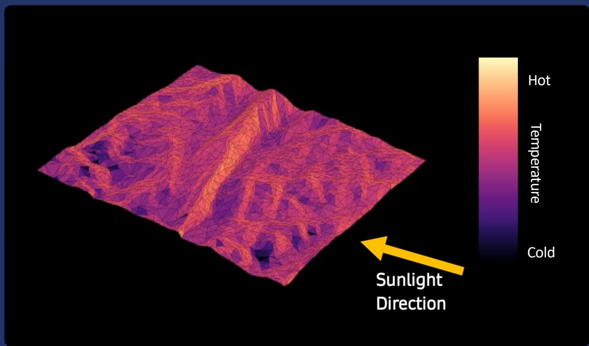


RESULT 1: An example insolation curve from a 1666 facet model of the bilobate comet 67P. The effects of scattered light can be seen either side of the main peak.

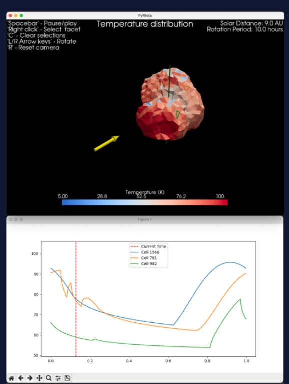
RESULT 2: Model shows good agreement with 'industry standard' thermophysical models in 1 dimension.



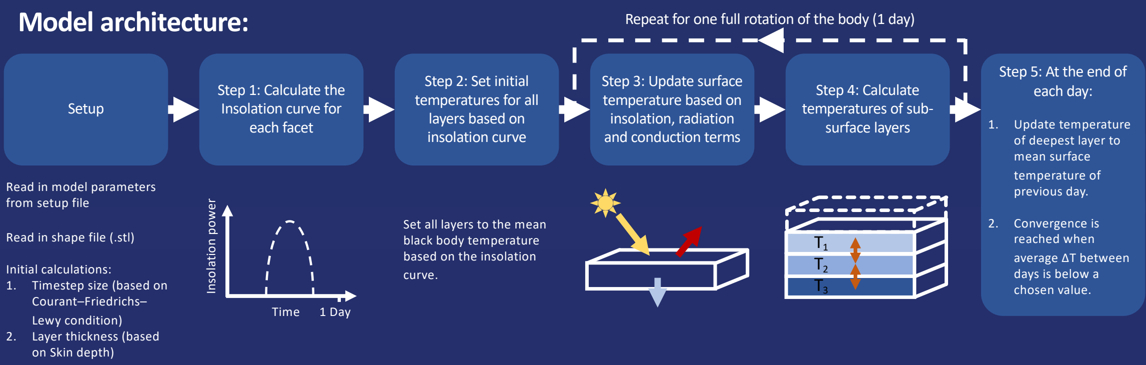
- Built to support NASA Lucy mission and ESA Comet Interceptor mission.
- Suited to a wide range of targets, including surfaces with active processes (e.g., transient heating events).
- User-friendly and operates quickly.
- Runs fast - seconds for basic models, a few minutes for complex shape models with 16,000 facets (as tested for comet 67P).
- Efficiently handles subsurface thermal conduction.
- Parallelised for faster processing of large, high-resolution shape models, allowing exploration of different parameter spaces within the same timeframe.



LEFT: Example output showing an area of Enceladus' South Polar Terrain. The shape model used was converted directly from a '.bds' SPICE file produced by Park et al., from Cassini data [3]. While the physical parameters used for this demonstration were not chosen to accurately represent the modelled body, the map gives an indication of the role terrain can have - producing a wide range of temperatures at high latitudes.



Model architecture:



LIMITATIONS & FUTURE WORK: While the model accounts for radiative self-heating and light scattering, it does not yet incorporate sublimation effects. Surface roughness modelling has been successfully demonstrated using a fractal landscape approach, though alternative methods are being explored to reduce computational intensity. Future work will focus on integrating SPICE kernels for mission-specific accuracy and implementing GPU acceleration to support high-resolution shape models more efficiently.

ONGOING VALIDATION: While the model shows good agreement with e.g., thermprojrs [1] in most regimes, it deviates in low illumination conditions for surfaces with high thermal inertia. It is expected to agree in all conditions, so this is an area currently under investigation.

CONCLUSIONS: We present our new Python-based thermal model that accurately predicts diurnal temperature variations on airless bodies, incorporating shadowing effects to improve accuracy in regions with complex topography. The model shows strong agreement with established thermophysical models and operates efficiently on standard hardware, making it a robust tool for scientific analysis and mission planning. This model enhances the accuracy of temperature predictions and makes advanced thermal modelling techniques available to a wider scientific community. The future aim is to use this tool, along with new and existing remote sensing data to better understand the surfaces of such airless bodies in our solar system.

References:
[1] Spencer, J.R., Lebofsky, L.A., and Sykes, M.V., 1989. Systematic biases in radiometric diameter determinations. Icarus, 78(2), pp.337-354.
[2] Guilbert-Lepoutre, A., and Jewitt, D., 2011. Thermal shadows and compositional structure in comet nuclei. The Astrophysical Journal, 743(1), p.31.
[3] Park, R. S., Mastrodemos, N., Jacobson, R. A., et al., 2024. The global shape, gravity field, and libration of Enceladus. Journal of Geophysical Research: Planets, 129, e2023JE008054.

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