

# SNTHERM24: An Improved Snow, Firn, and Glacier Ice Evolution Model for Earth and Mars

Aditya R. Khuller<sup>1</sup>, Rachel E. Jordan<sup>2</sup>, Stephen G. Warren<sup>3</sup>, Gary D. Clow<sup>4</sup>, Philip R. Christensen<sup>5</sup>

<sup>1</sup>Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, <sup>2</sup>Jordan Environmental Modeling, PC, Hanover, NH (retired from CRREL), <sup>3</sup>Department of Atmospheric Sciences, University of Washington, Seattle, WA, <sup>4</sup>Institute of Arctic and Alpine Research, University of Colorado Boulder, Boulder, CO, <sup>5</sup>School of Earth and Space Exploration, Arizona State University, Tempe, AZ.

## I. Background

- SNTHERM89, a one-dimensional model of energy and mass balance has been used successfully to simulate the evolution of snow, sea ice, and glacier ice on Earth over the last 30 years<sup>1</sup>
- Here we present significant improvements in both the solar radiation and atmospheric turbulent flux calculations

## II. Objectives

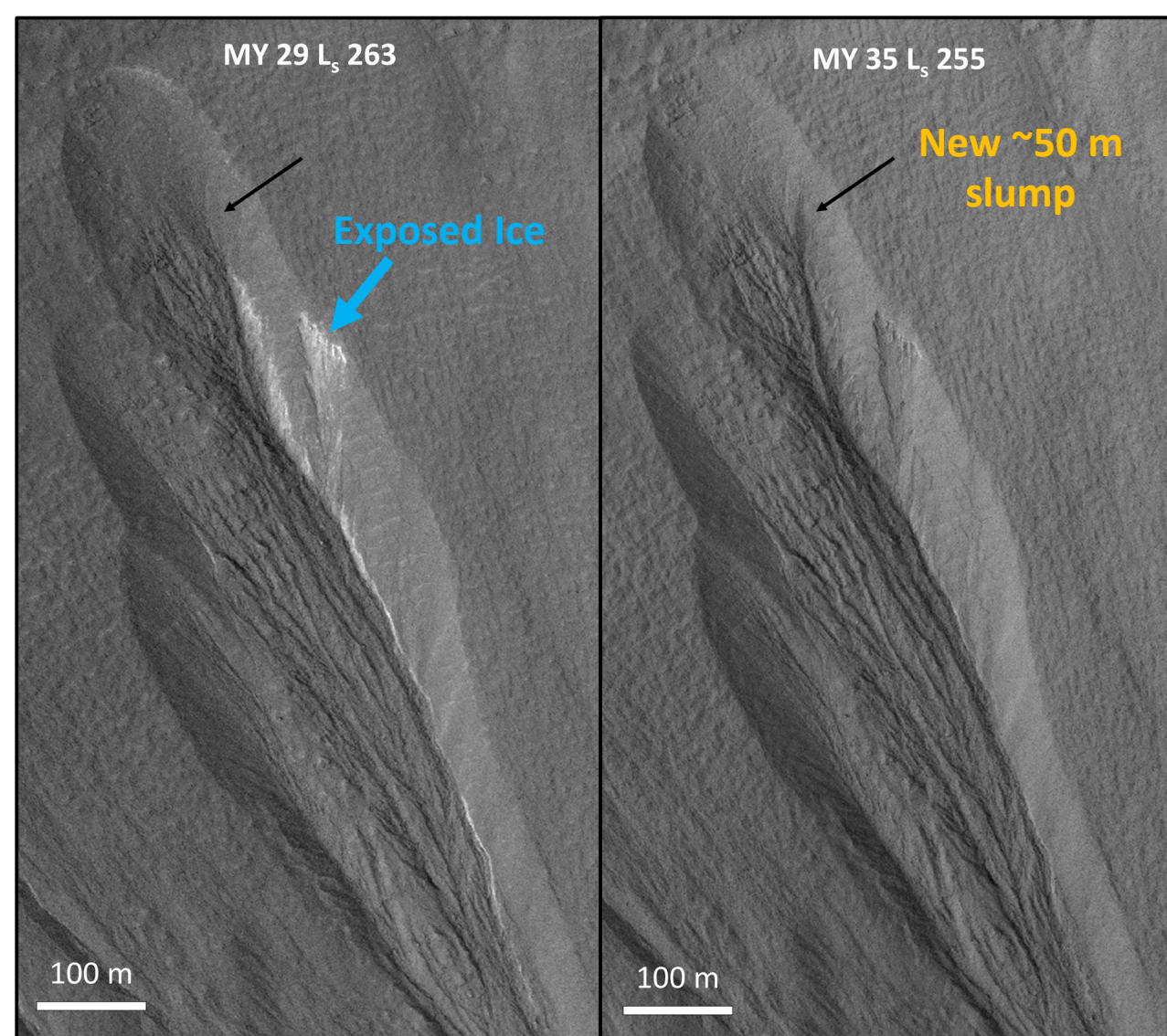
- Determine the energy balance of snow, firn, and glacier ice on Earth and Mars
- Constrain the conditions under which snow and ice can melt in the shallow subsurface (top few meters)

## III. Approach & Results

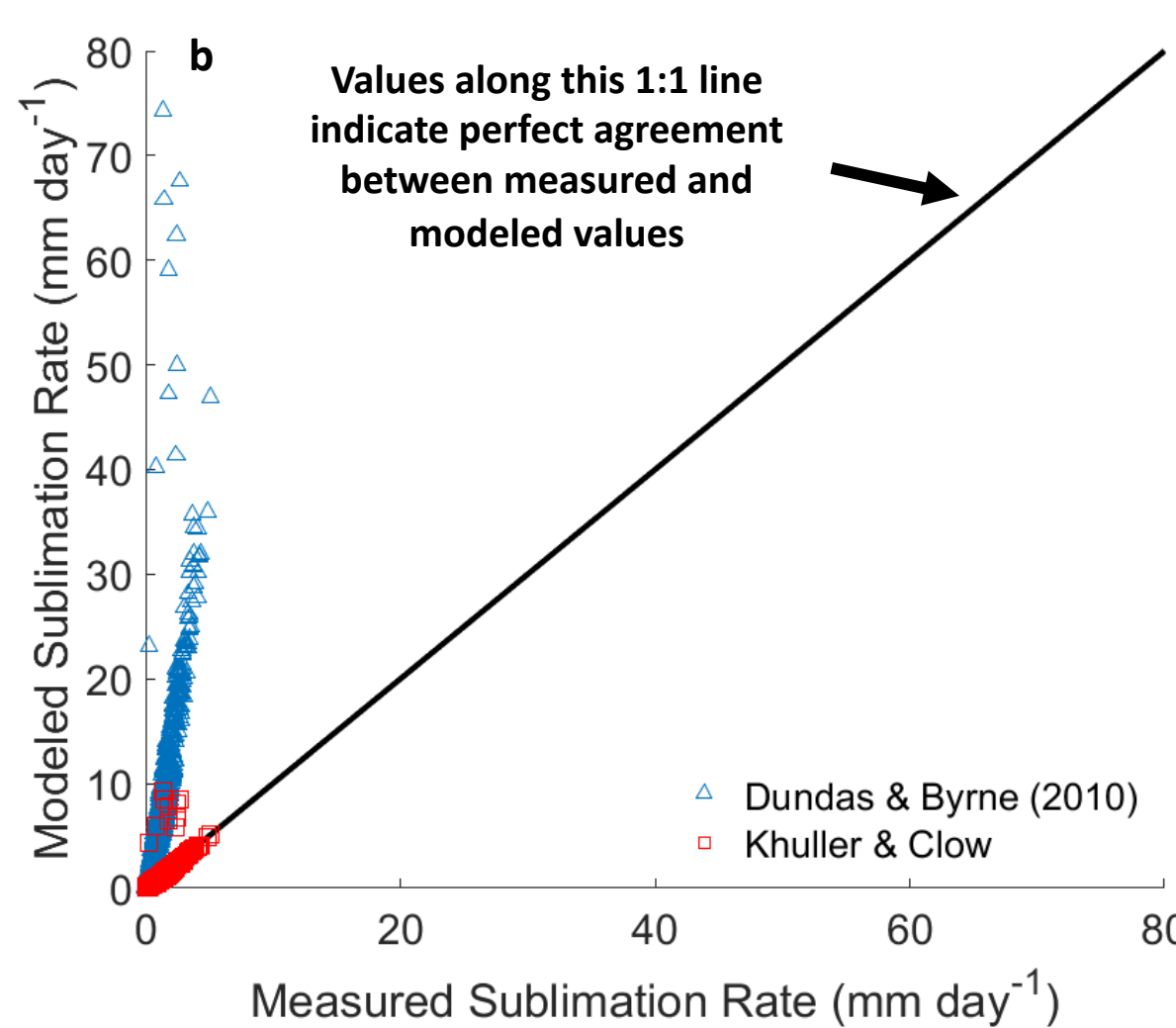
- Developed first radiative transfer model for dusty snow and glacier ice on Earth and Mars<sup>2,3</sup>
- > Validated against in-situ measurements of spectral albedo and spectral, in-ice irradiance on Earth and Mars.
- > Assuming that the irradiances below the surface are zero or using a broadband extinction value can lead to errors up to ~10 K in subsurface heating.
- Developed new, unified model to predict atmospheric turbulent fluxes and evaporation/sublimation rates on any terrestrial planetary body<sup>4</sup>
- > Validated using in-situ measurements from Earth, Mars, and Titan.
- > Model shows up to ~5x better agreement with measurements compared to methods commonly used on Mars.

### Contact Information:

[akhuller@jpl.nasa.gov](mailto:akhuller@jpl.nasa.gov); 520-450-7199



**Figure 1.** Dusty H<sub>2</sub>O ice on Mars<sup>5</sup>, disappearing over six Mars Years (MY). The black arrow indicates a ~50 m slump that was not present in MY 29. Whether the ice melted and/or sublimated is currently unknown. We will assess whether liquid water is being produced within similar mid-latitude ice exposures.

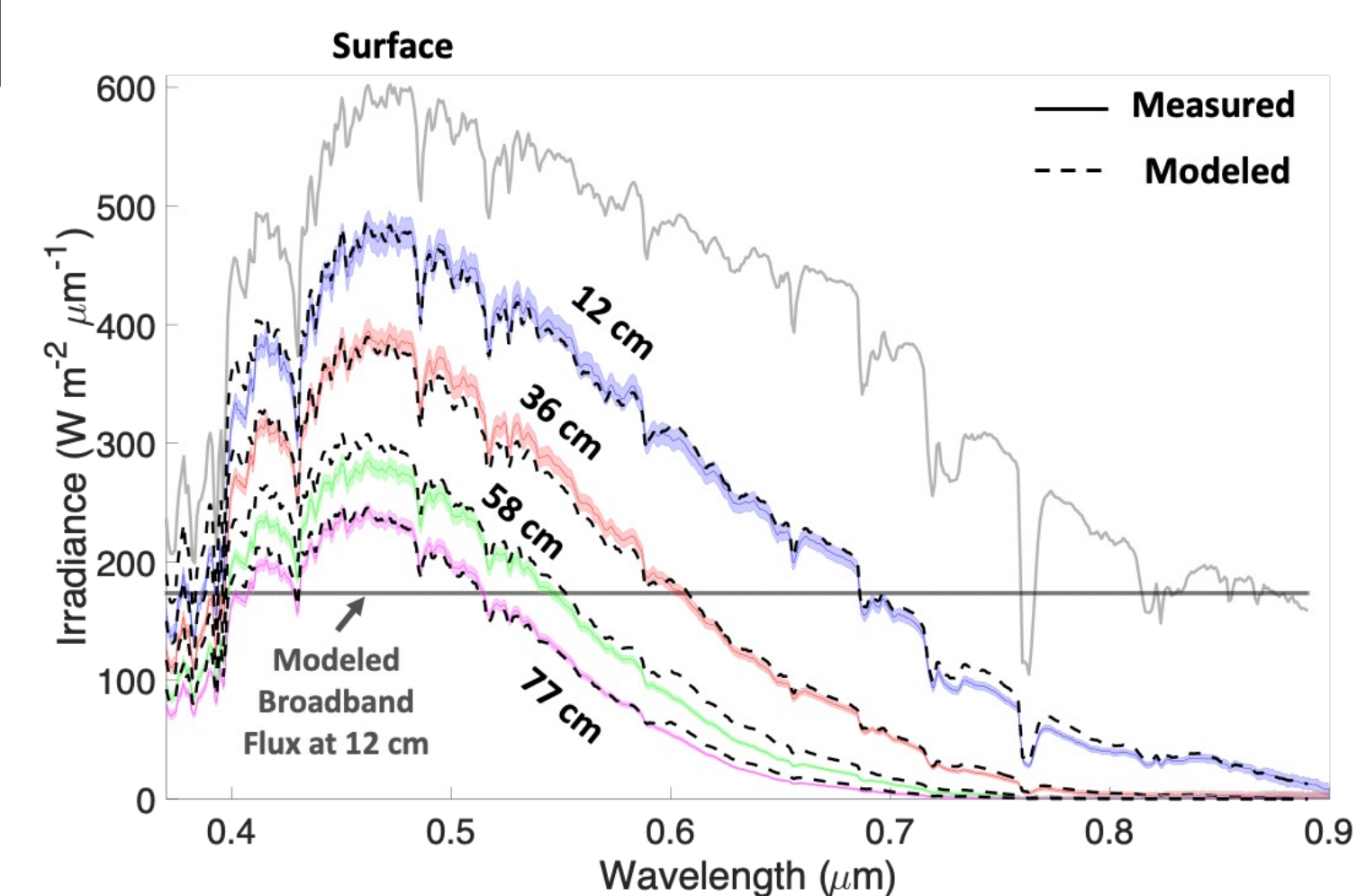


**Figure 3.** (a-b) Modeled vs. measured sublimation rate of a perennially H<sub>2</sub>O ice-covered lake in the Dry Valleys of Antarctica<sup>4</sup>. Results from a common martian ice model<sup>7</sup> are shown in blue.

**References:** 1. Jordan, R.E. (1991), A one-dimensional temperature model for a snow cover: Technical documentation for SNTHERM. 89. CRREL. 2. Khuller, A.R., Christensen, P.R., Warren, S.G. (2021), Spectral albedo of dusty martian H<sub>2</sub>O snow and ice. *JGR: Planets*. 3. Khuller, A.R., Warren, S.G., Clow, G.D., Christensen, P.R., (accepted). Potential for Photosynthesis on Mars Within Snow and Ice. *Nature Comm. E & E*. 4. Khuller & Clow (2024), Turbulent Fluxes & Evaporation/Sublimation Rates on Earth, Mars, Titan, and Exoplanets. *JGR: Planets*. 5. Khuller, A.R. & Christensen, P.R. (2021) Evidence of Exposed Dusty Water Ice within Martian Gullies, *JGR: Planets*. 6. Cooper, M.G. et al. (2021), Spectral attenuation coefficients from measurements of light transmission in bare ice on the Greenland Ice Sheet. *The Cryosphere*. 7. Dundas, C.M. & Byrne, S. (2010), Modeling sublimation of ice exposed by new impacts in the martian mid-latitudes. *Icarus*.

## IV. Significance

- Our improved model can be used to:
- Improve constraints on ice mass balance
  - Predict locations of subsurface melting, which can impact:
    - the evolution of martian geology
    - the potential for subsurface life
    - the future exploration of Mars



**Figure 2.** Modeled spectral solar irradiance at various depths in comparison with measurements made in glacier ice<sup>6</sup>. Many existing snow and ice models assume that the irradiances below the surface are zero or simply use a broadband extinction value, which can lead to errors up to ~10 K in subsurface heating.

## V. Ongoing Work

- Incorporating new solar and turbulent flux models into SNTHERM
- Validating model using snow, firn, and glacier ice measurements from Earth
- Evaluate mass and energy balance for snow, firn and ice on Earth and Mars