Thermal Modeling of Mars Ground for Surface Missions

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Outline

- Ground modeling introduction
- Worst Case Cold and Worst Case Hot environments
- Local ground modeling
- Effects of Mars 2020 rover on local ground
    - Shadowing
    - MMRTG dissipation
- Subsurface ground temperatures
- Conclusions

Introduction

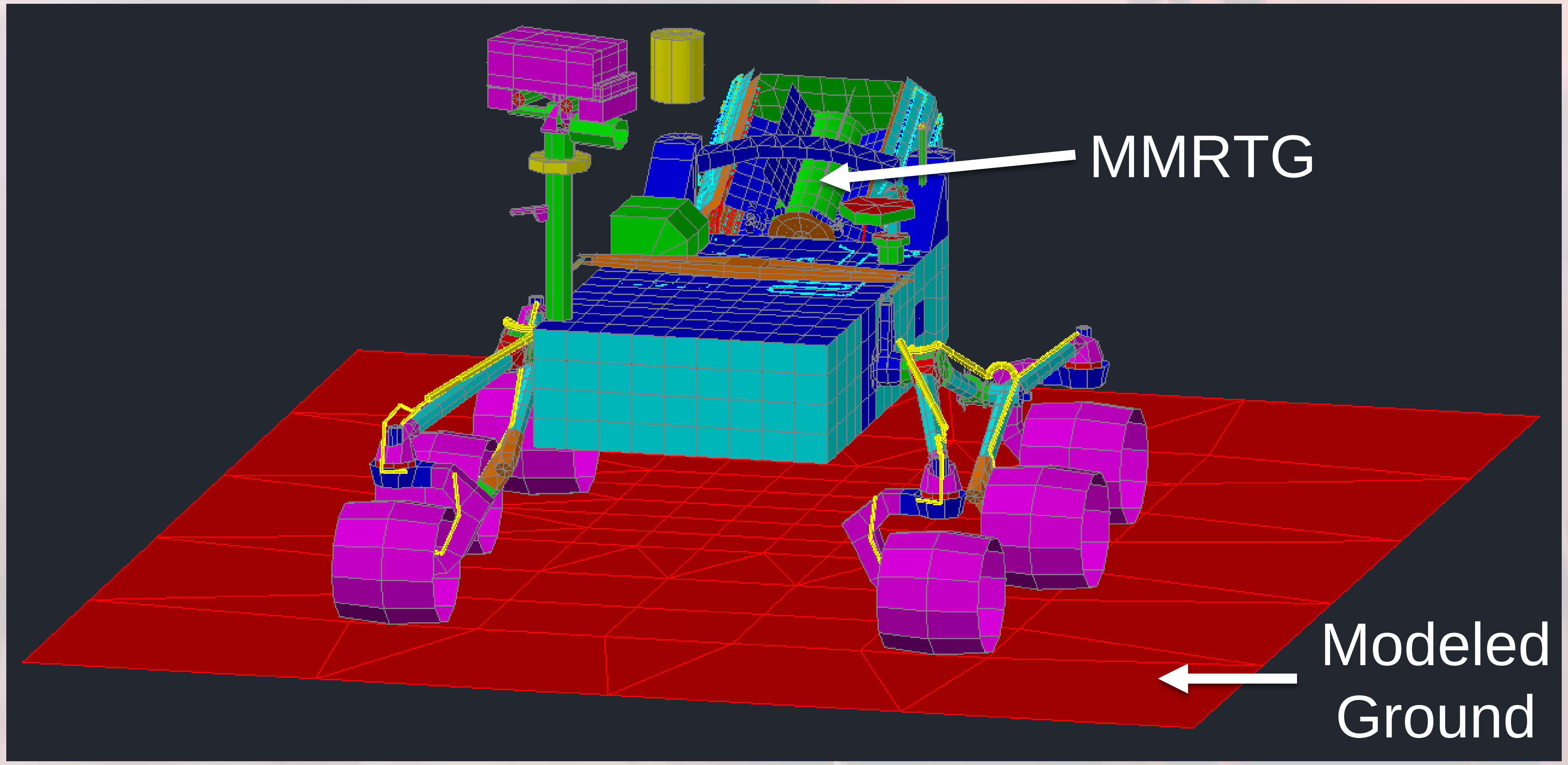
- Thermal modeling software has capability of including ground temperature as a boundary. This approach does not capture local ground interactions which could change the ground temperature.

- Interest in explicit ground modeling:

  1. Mars 2020 Rover Model: capture effects of rover shadowing and Multi Mission Radioisotope Thermoelectric Generator (MMRTG) heat dissipation

  2. Sample Acquisition: understand temperature history of subsurface ground

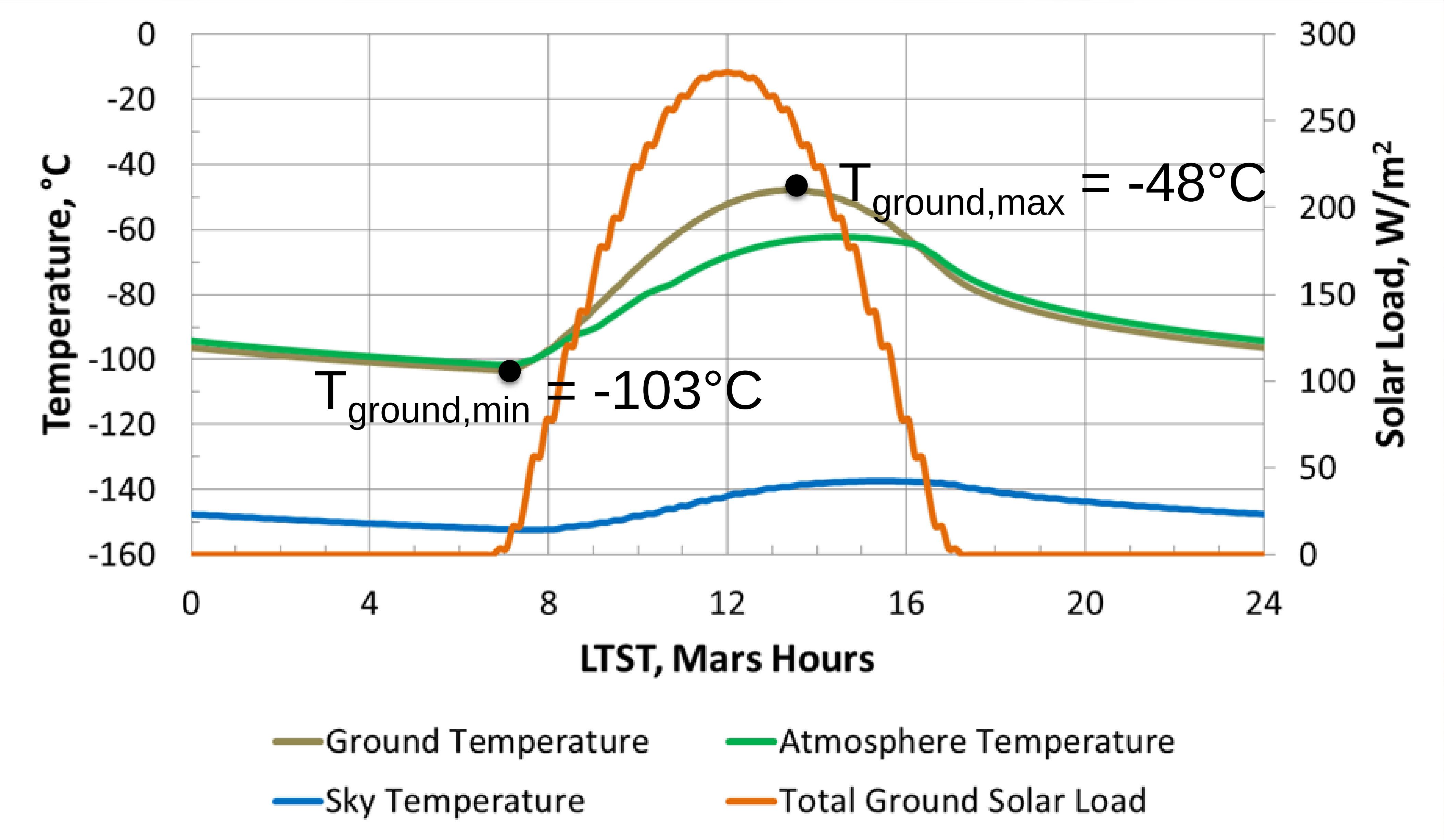
Mars 2020 Rover System Thermal Model



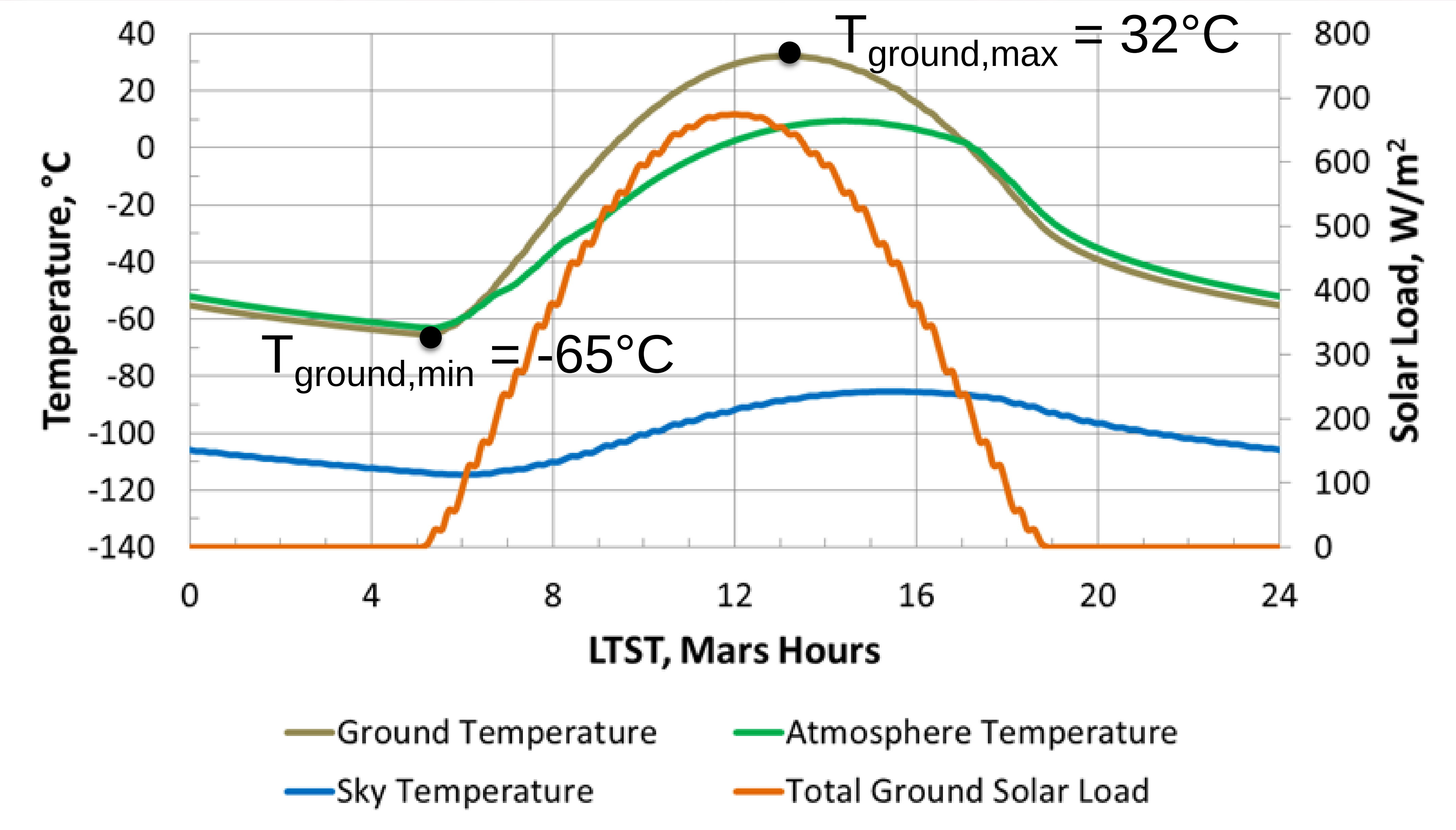
WCC and WCH Environments

- A detailed Mars Weather Research and Forecasting General Circulation Model (MarsWRF GCM) is used to generate environment predictions at a given latitude
  - Ground Temperature, Atmosphere Temperature, Sky Temperature, Solar Load
- Bounding Worst Case Cold (WCC) and Worst Case Hot (WCH) environments generated from potential Mars 2020 landing sites. Results (Holden Crater, 26° S) used in thermal analysis as far-field boundary conditions

<u>WCC</u>

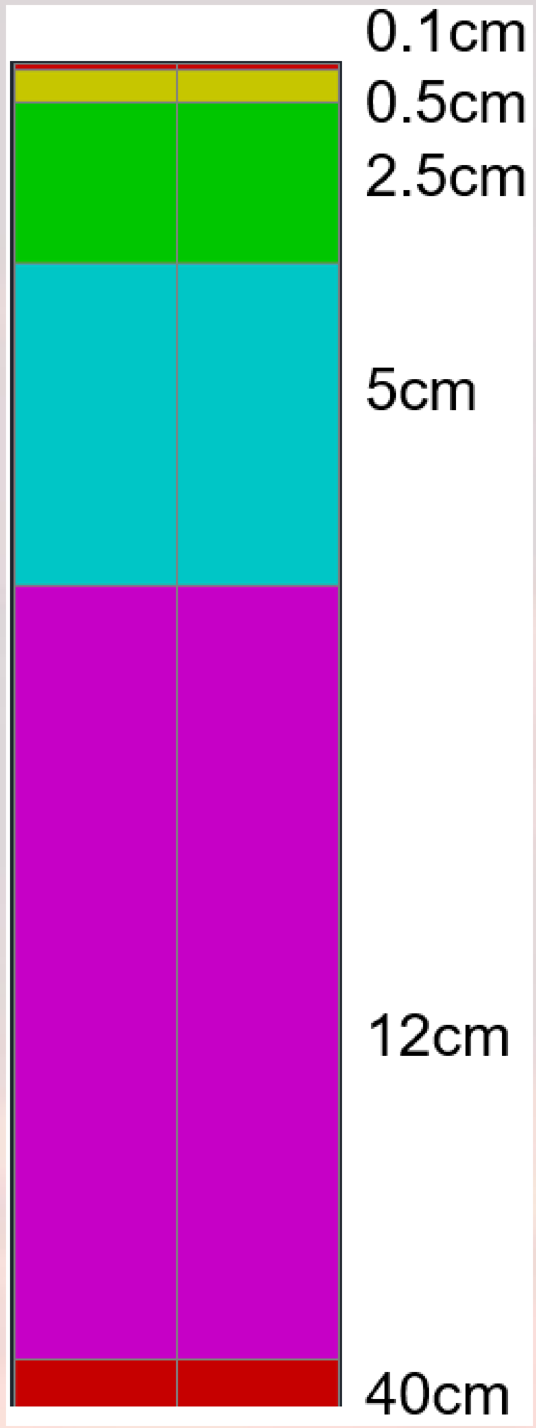


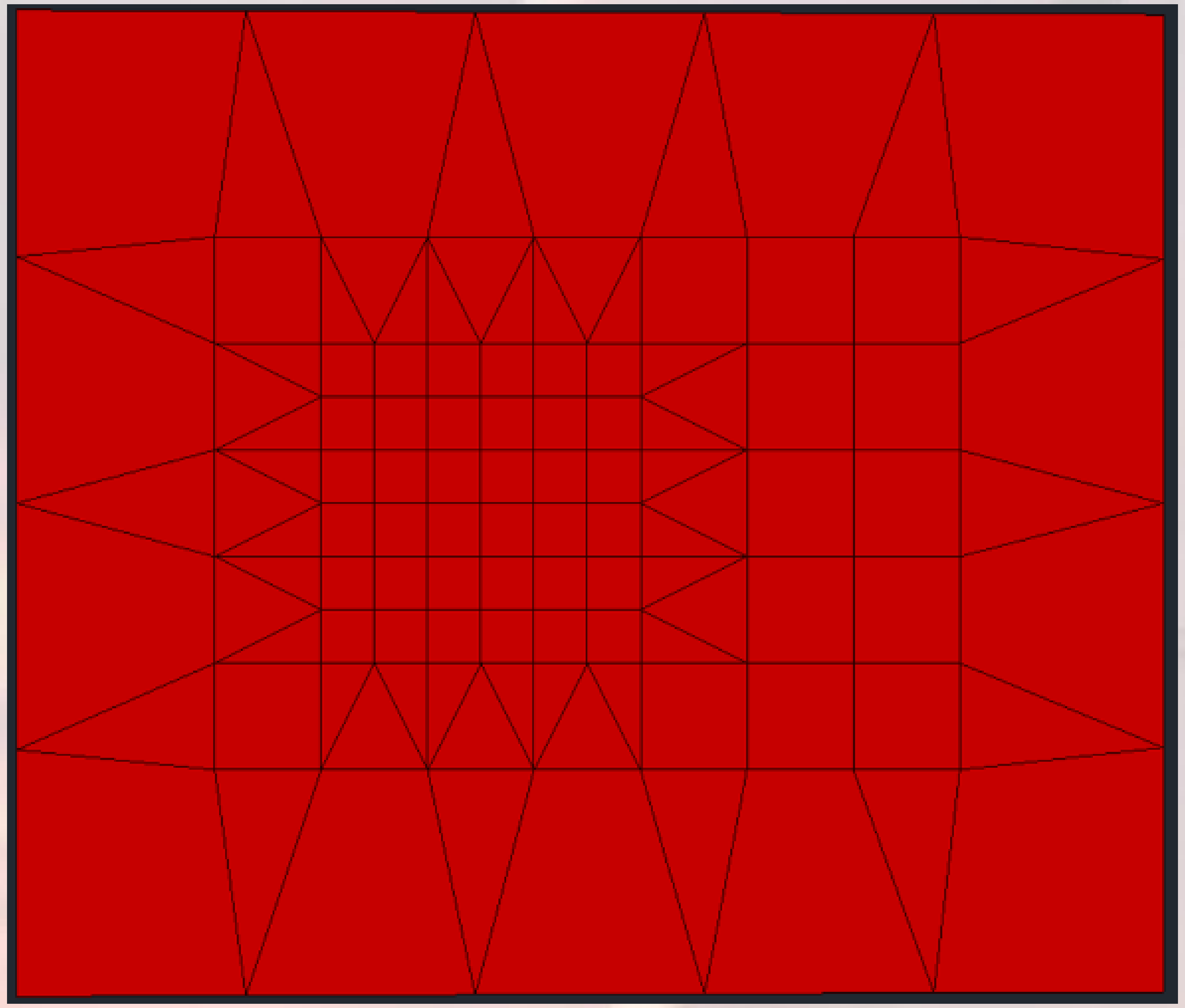
<u>WCH</u>

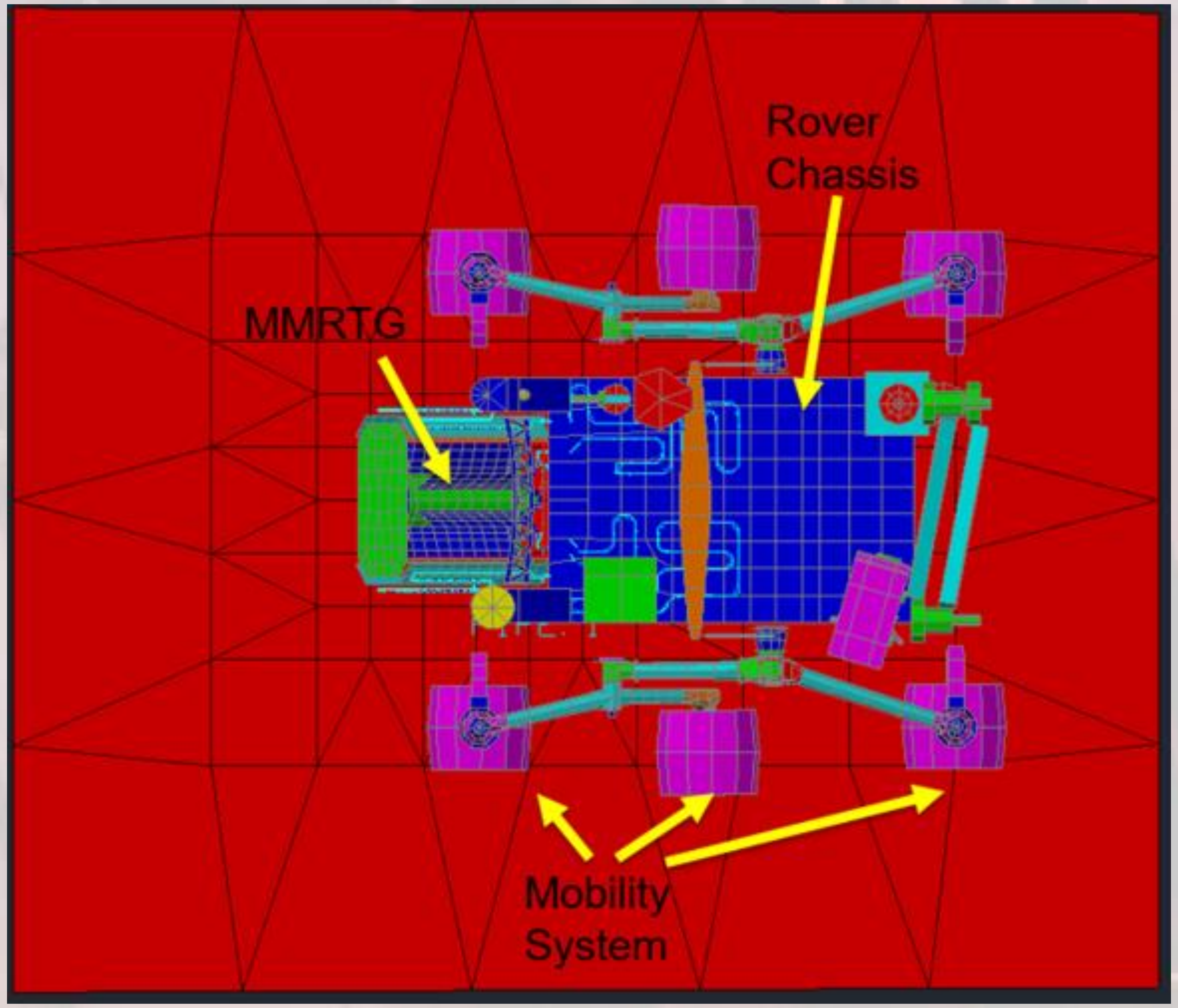


Ground Modeling

- Use of MarsWRF GCM environments is appropriate for far-field boundary conditions, but are not accurate for local regions that interact with hardware of interest
- A 5.4m x 4.6m patch of ground is modeled to depth of 60cm (7 node discretization)
- Rover model placed above ground surface







Ground Modeling

- Ground thermophysical and thermoptical properties are obtained from Thermal Emission Spectrometer (TES) measurements, onboard the Mars Global Surveyor

Thermal Inertia, *I*	**362 $Jm^{-2}K^{-1}s^{-1/2}$**
Thermal Conductivity, *k*	**0.1092 $Wm^{-1}K^{-1}$**
Density, *ρ*	**1500 kgm^{-3}**
Heat Capacity, c_p	**800 $Jkg^{-1}K^{-1}$**
Solar Absorptivity, *abs*	**0.868**
IR Emissivity, *ε*	**0.95**

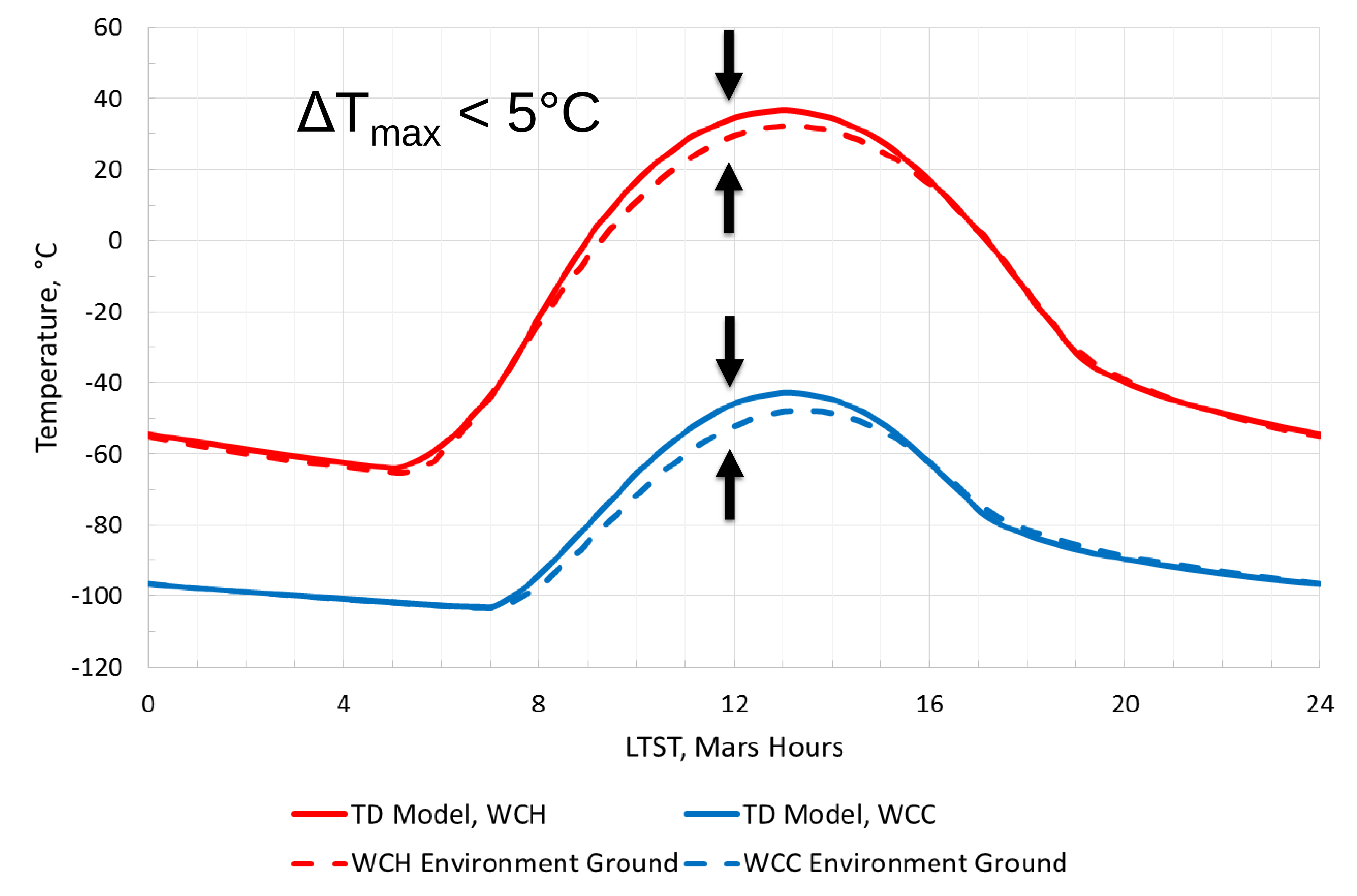
- Ground is modeled to 0.6m to account for full thermal penetration depth
  - Closed form solution of semi-infinite body with a sinusoidal varying wall temperature (*T*=24.6 hours):

$$d = 4.61\sqrt{\frac{2\alpha}{\omega}}$$

$$d = 6.52\sqrt{\frac{kT}{\rho c_p}} = 0.6m$$

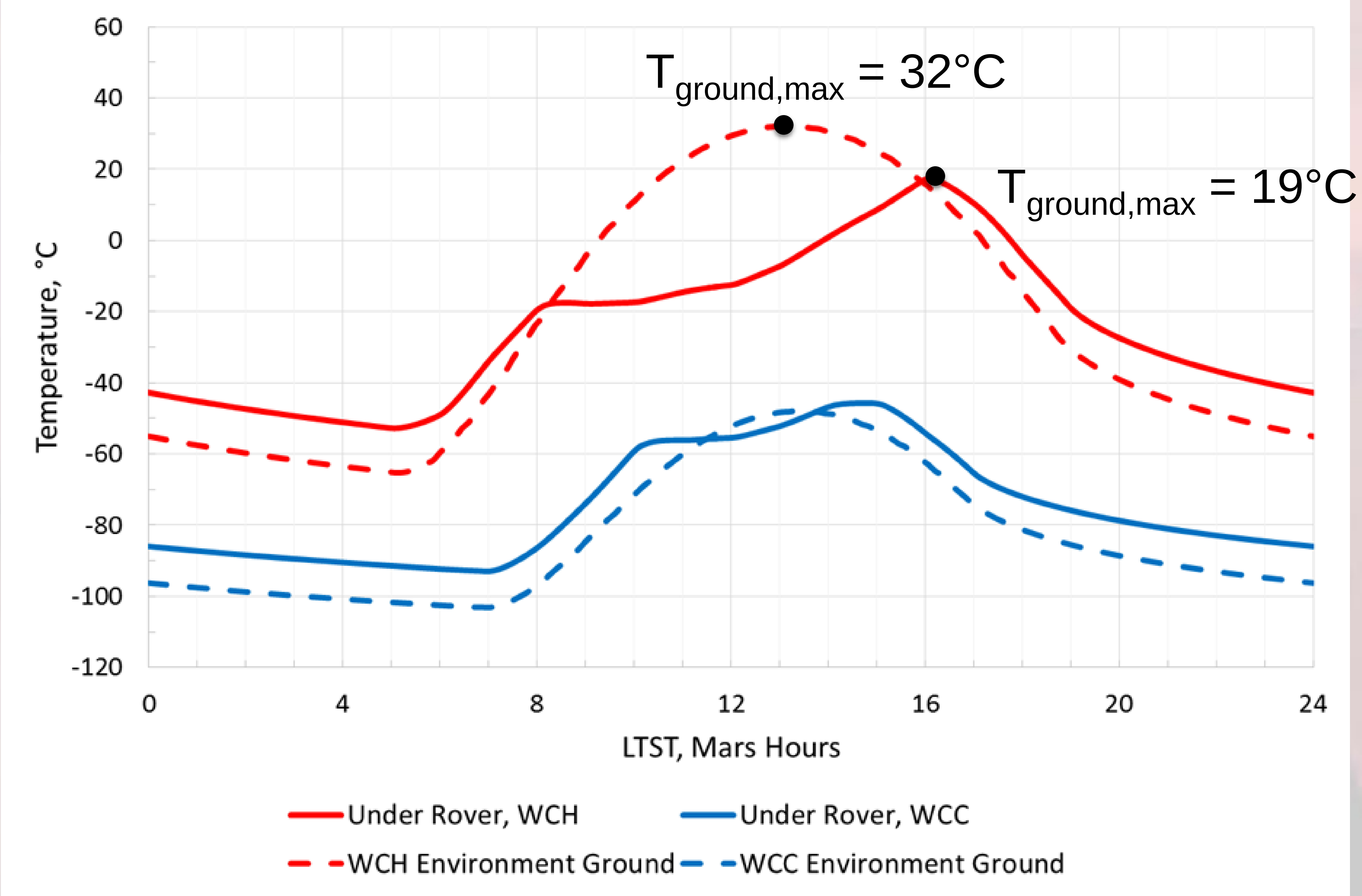
Ground Temperature Comparison

- Ground model first run without rover. Atmosphere-Ground convection was added in order to match ground temperature results to the MarsWRF GCM results.
  - $h=1.0\ W/m^2K$ for WCC
  - $h=1.5\ W/m^2K$ for WCH
- Explicitly modeled ground is within 5°C of the MarsWRF GCM environment results



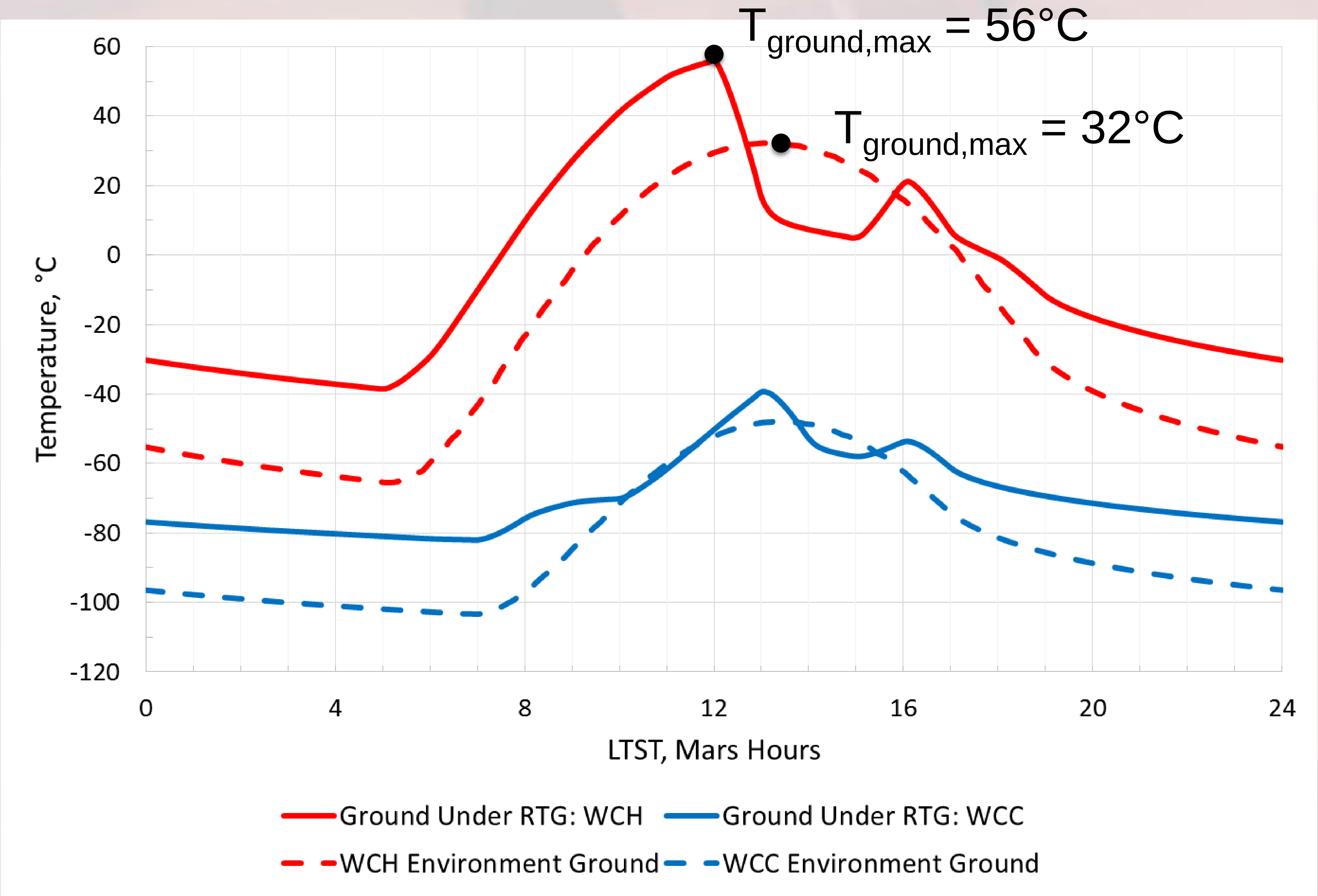
Shadowing from Rover Chassis

- The rover chassis shadows the ground resulting in:
  - Colder daytime temperatures as the chassis blocks incoming solar flux
  - Warmer nighttime temperatures as the chassis blocks radiation heat loss to the sky



MMRTG Heat Dissipation

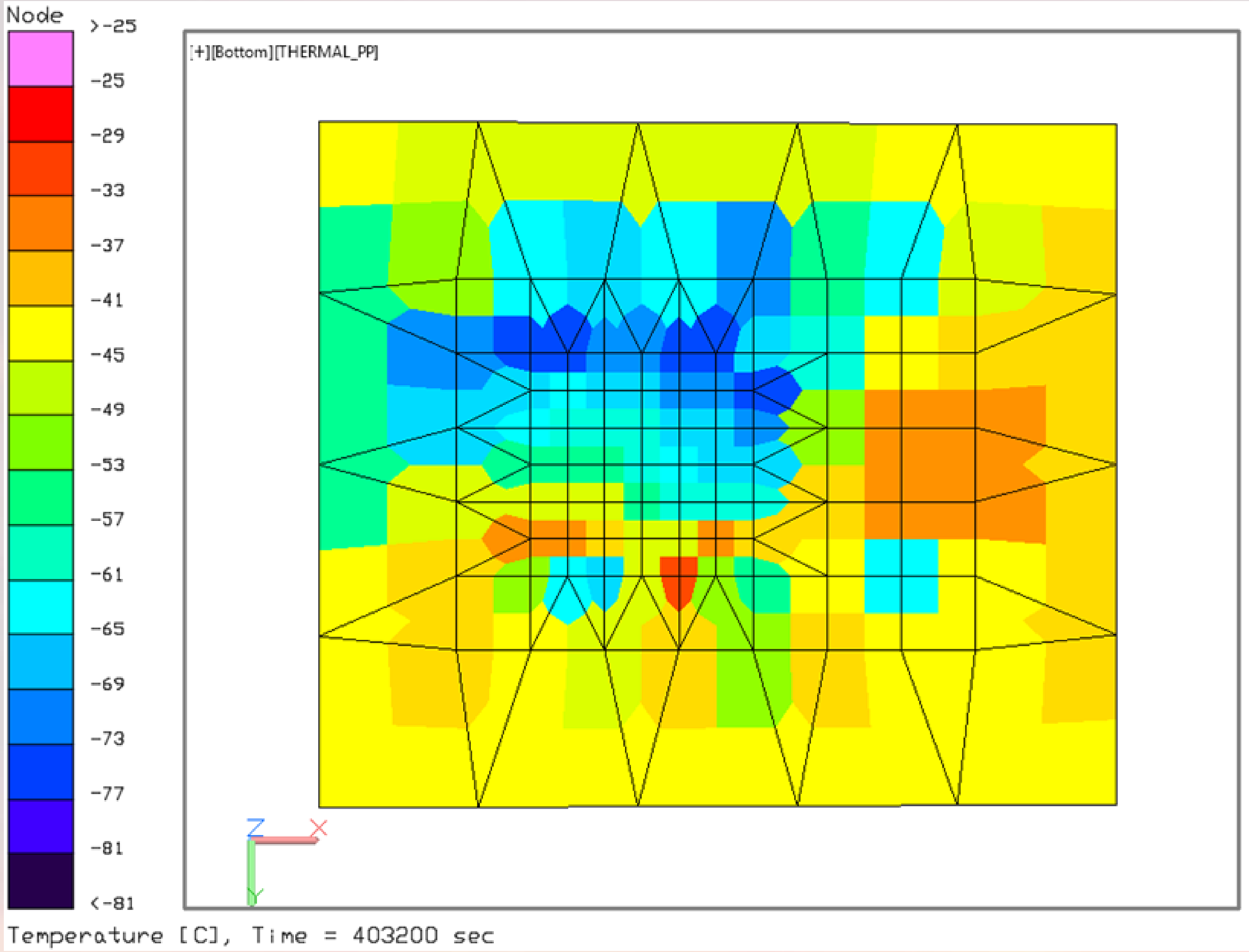
- The MMRTG operates as hot as 200°C and dissipates ~2000W of heat, resulting in a local ground temperature rise over the course of the entire day
- Effects of shadowing are still present



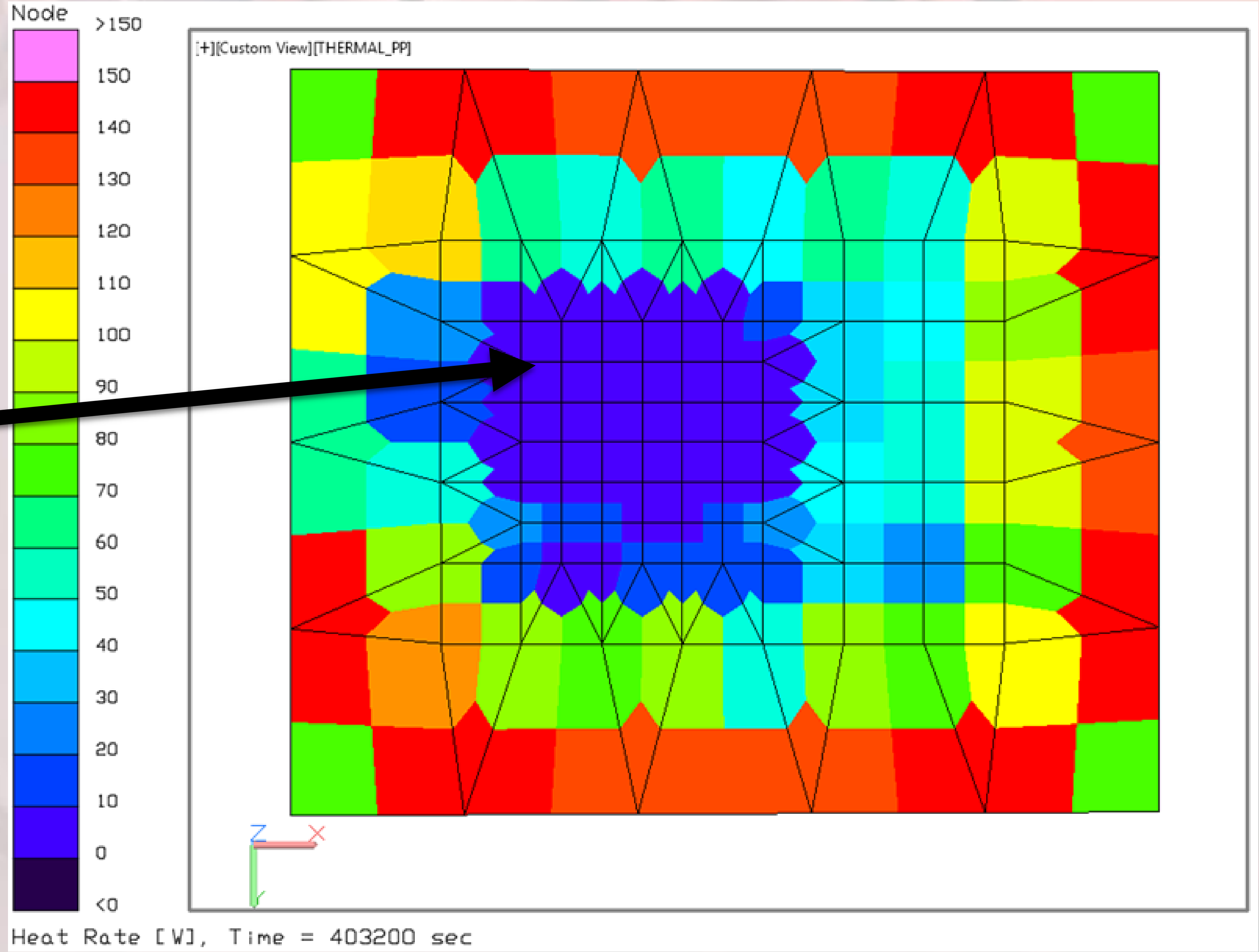
WCC Contour Plots

- Plots for warmest time of day (13:00 LTST)

Temperature (C)



Heat Rate (W)

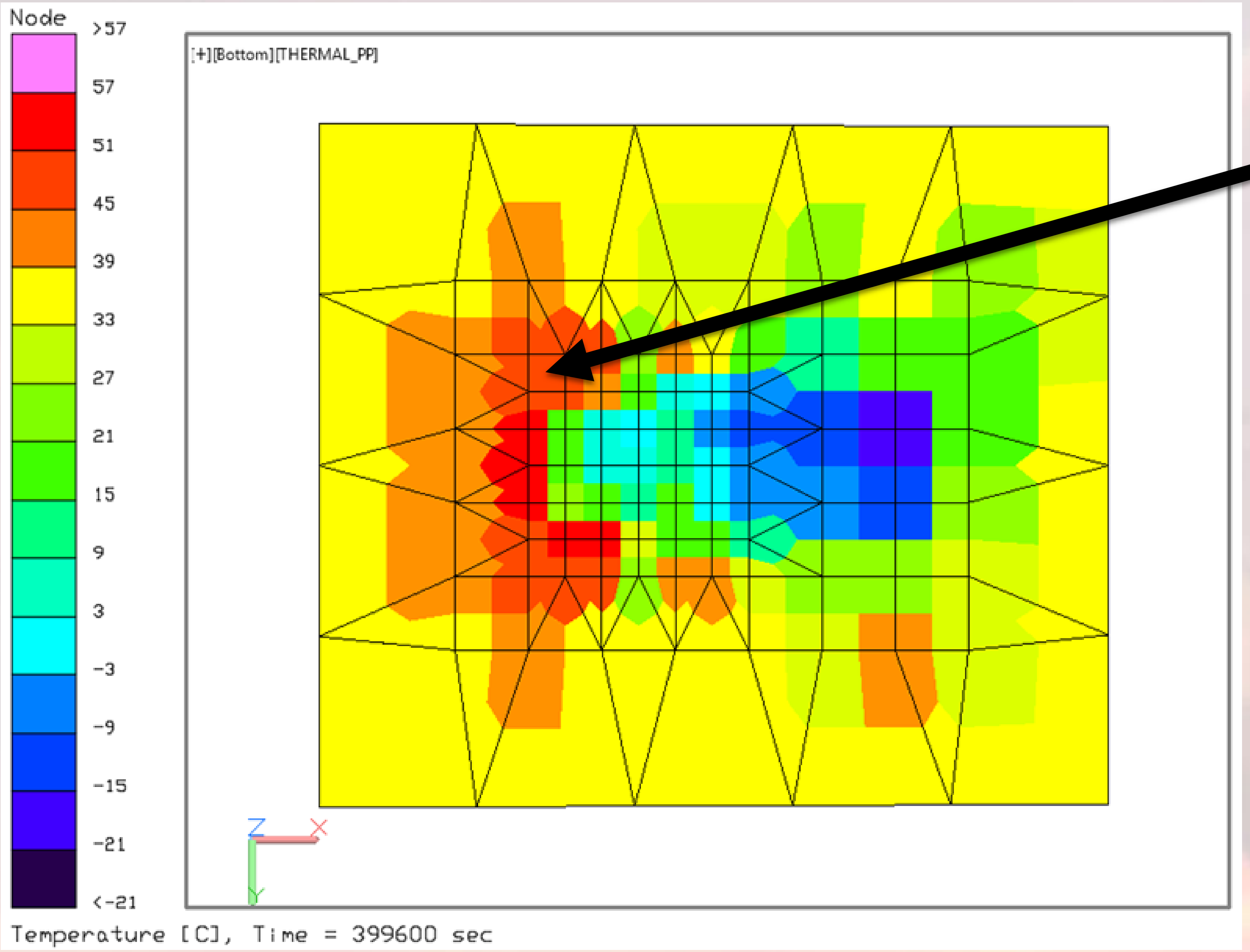


Effect of shadowing visible

WCH Contour Plots

- Plots for warmest time of day (12:00 LTST)

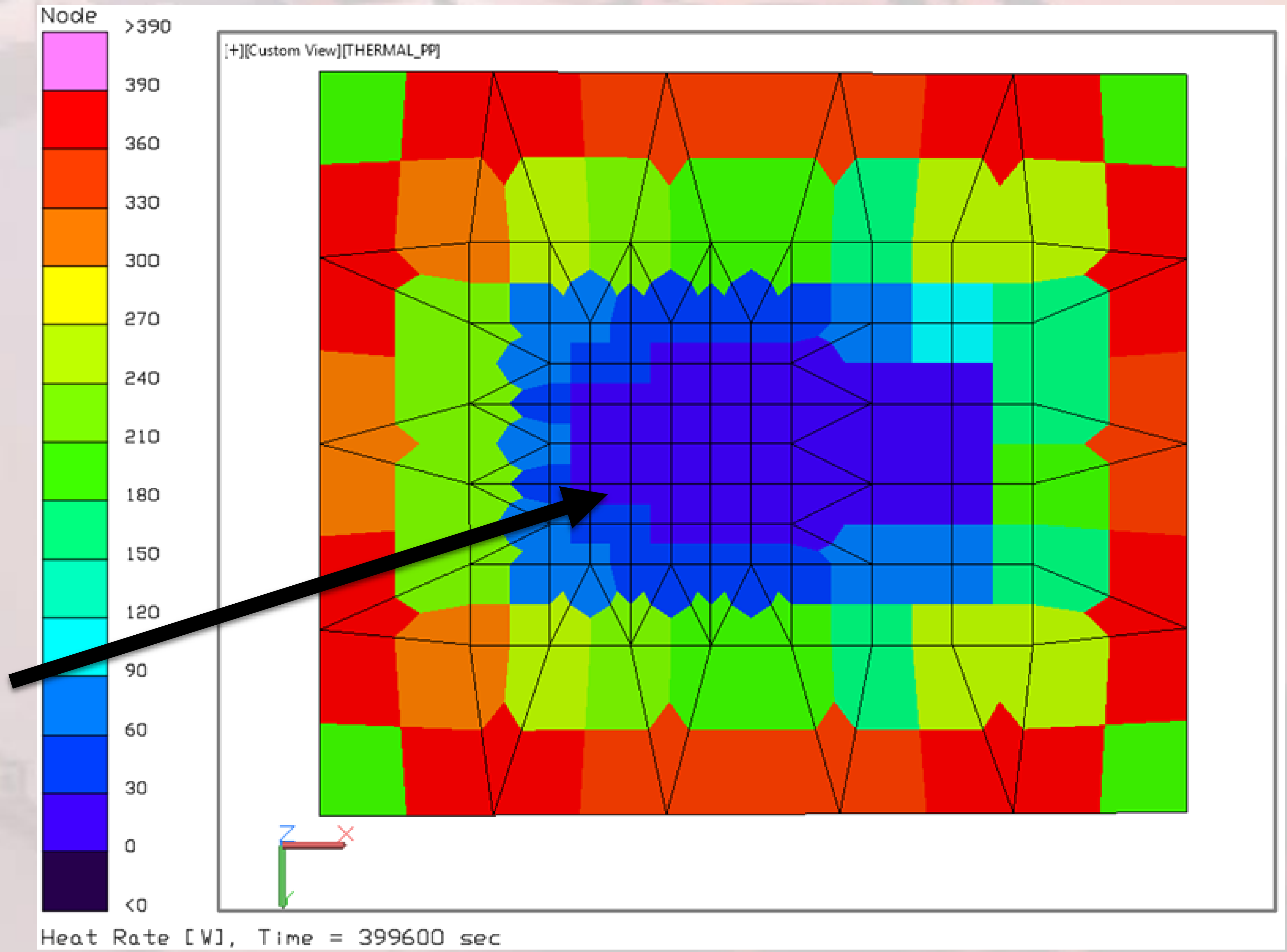
<u>Temperature (C)</u>



Effect of MMRTG visible

Effect of shadowing visible

<u>Heat Rate (W)</u>



Subsurface Ground

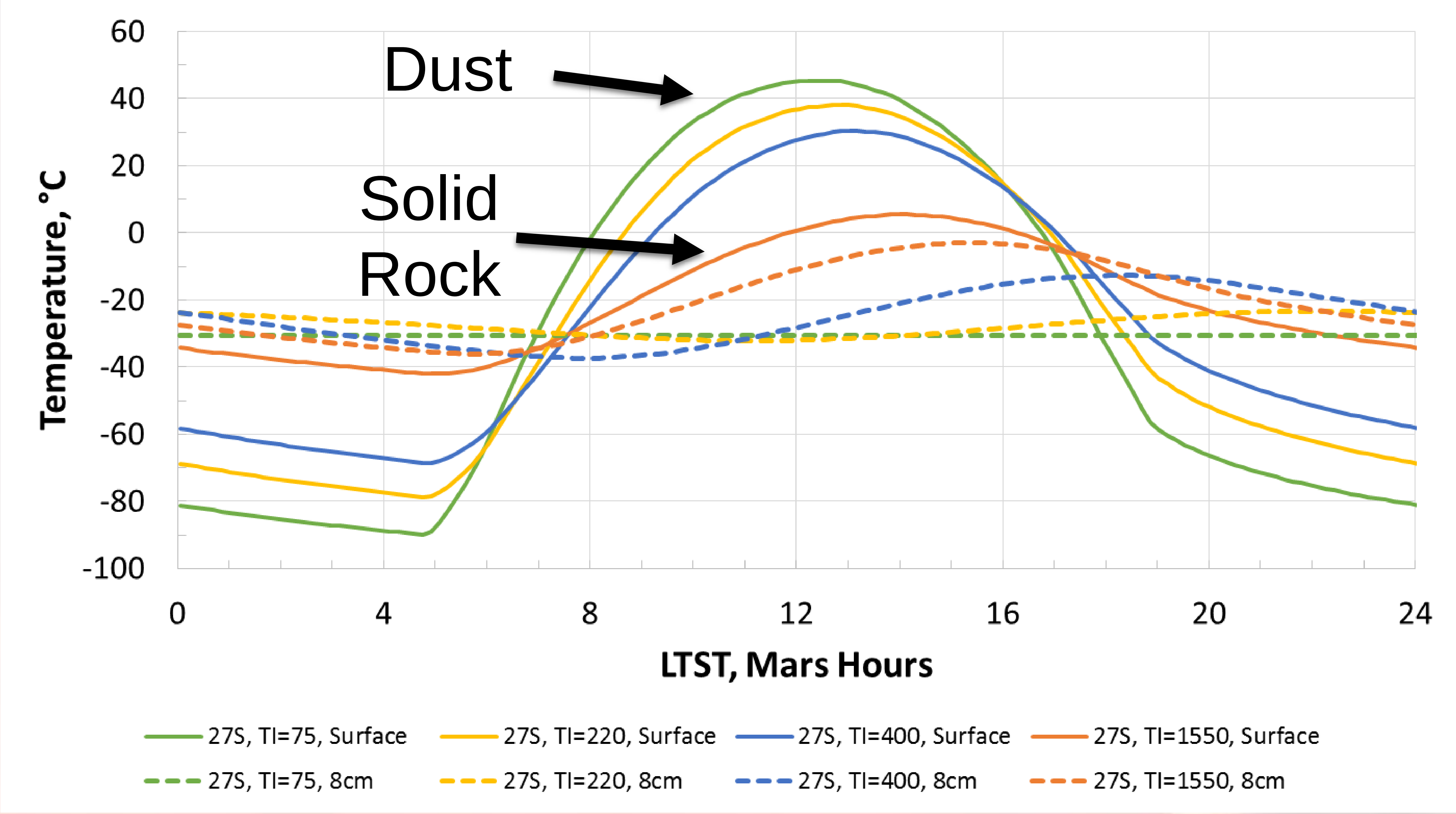
- One of the goals for the Mars 2020 mission is collect rock and regolith samples from a depth of up to 8cm
- The temperature at 8cm depth is different than on the surface, so knowing the temperature history of the sample may be useful during science measurements
- Collected samples will vary from loose dust to solid rock, resulting in a wide range of expected ground thermal conductivities and penetration depths:

	Thermal Inertia, *I* $Jm^{-2}K^{-1}s^{-1/2}$	**Thermal Conductivity, *k*** $Wm^{-1}K^{-1}$	**Penetration Depth, *d*** m
Dust	**75**	**0.0047**	**0.121**
Loose (Sandier) Regolith	**220**	**0.04**	**0.356**
Consolidated (Rockier) Regolith	**400**	**0.1333**	**0.648**
Solid Rock	**1550**	**2.0**	**2.509**

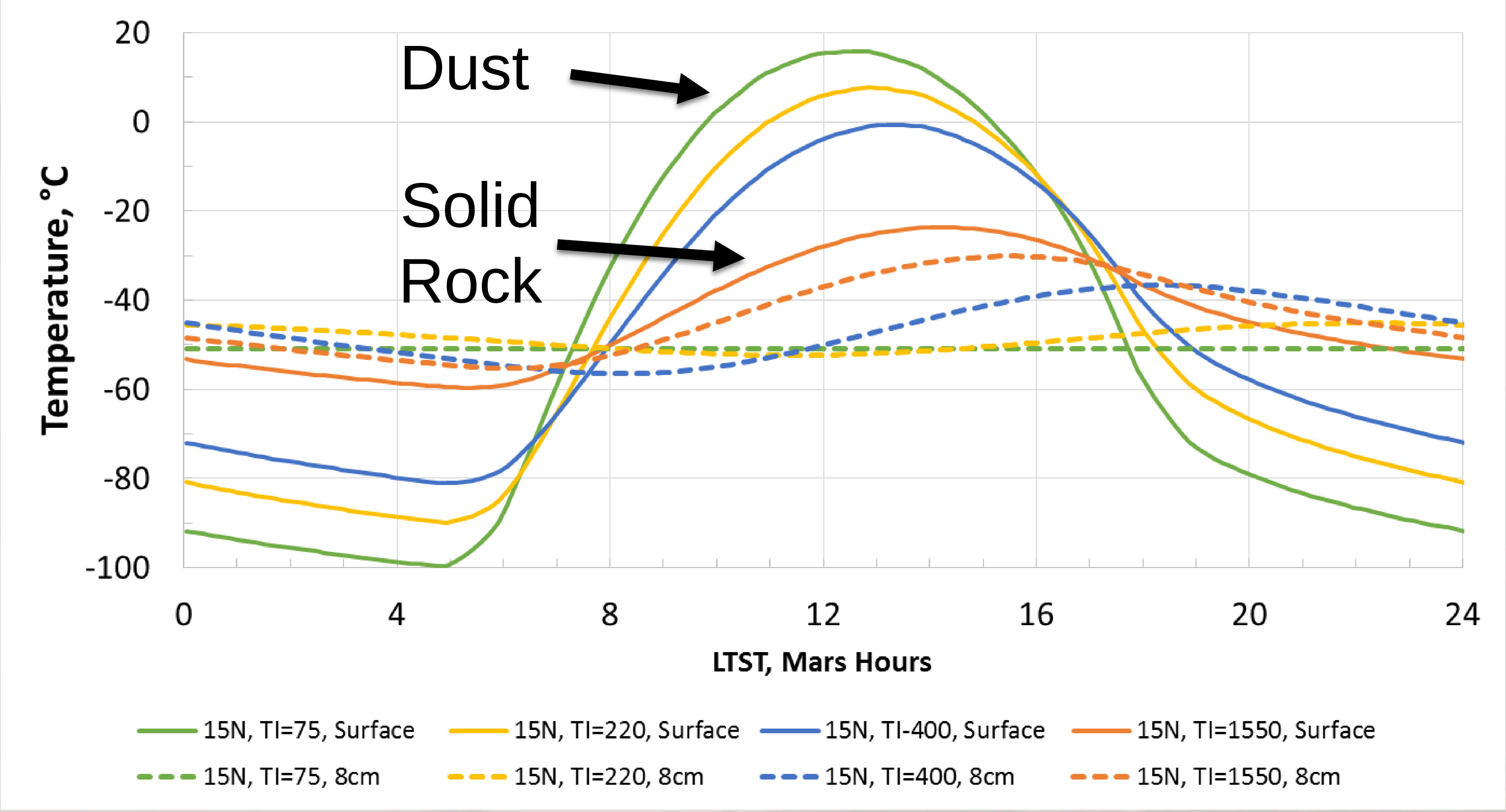
Subsurface Ground

- Diurnal temperature variation at 8cm depth is less than at the surface
- Low thermal inertia ground types result in more extreme surface variation and less extreme subsurface variations
- High thermal inertia ground types result in less extreme surface variation and more extreme subsurface variations

Temperatures at 27°S Summer

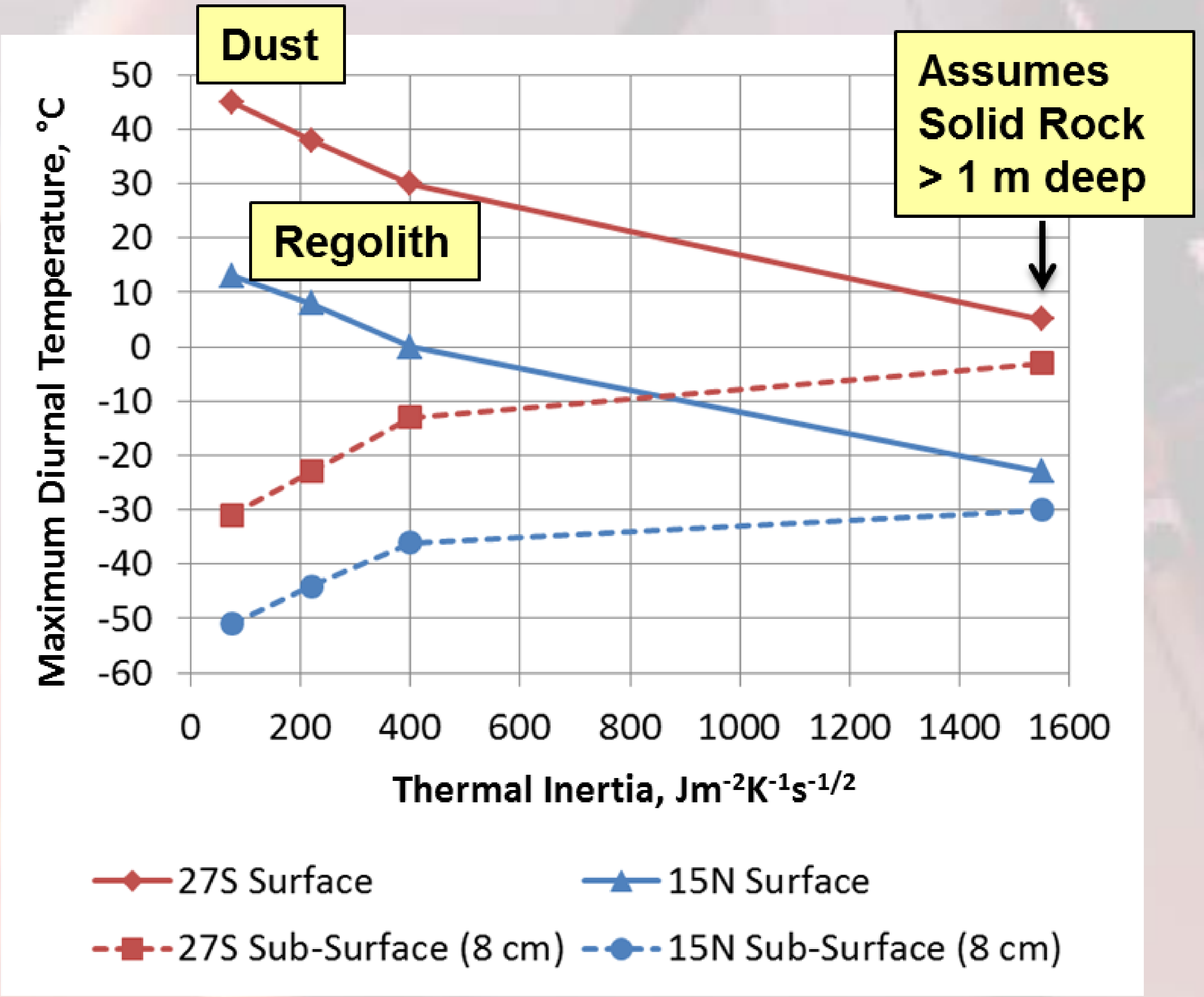


Temperatures at 15°N Summer



Subsurface Ground

- Low thermal inertia ground types have warmer peak surface temperatures, cooler subsurface temperatures, and larger gradients
- High thermal inertia ground types have cooler peak surface temperatures, warmer subsurface temperatures, and smaller gradients



Conclusions

- A simple method of modeling Mars ground has been demonstrated that accurately match the more complex MarsWRF GCM predictions
- Effects of Mars 2020 rover shadowing and MMRTG dissipation on local ground have been analyzed
- Surface and subsurface ground temperatures have been analyzed for a wide range of ground types and allows for estimating temperature history of collected Mars samples

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