



# Modeling mountain gravity waves in the Martian upper atmosphere



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## Abstract

Mountain waves (also known as orographic gravity waves) are atmospheric gravity waves generated when winds blow across mountains. It is known that gravity waves have a significant impact on the upper atmosphere. A relatively small amount of energy and momentum transported from tropospheric altitudes to the upper atmosphere can have a profound effect. Recent developments have indicated that upper atmospheric winds on Mars are directly related to the mountains below. The mountains on Mars are extremely high, much higher those on Earth. Hence, we expect mountain waves to be more significant on Mars than possibly anywhere else in the Solar System. Despite this, no modeling of mountain waves has occurred in recent times!

Dr. Michael Hickey has developed a spectral version of his full-wave gravity wave model that has allowed him to model the generation, propagation and dissipation of mountain waves in the Venus atmosphere. This is on-going research. For this project, the Venus model is applied to the Mars data. The calculations are run through a Fortran script and then used for plotting in Matlab. The model will be predominately analyzed according to the following parameters: mean temperature and winds; viscosity; thermal conductivity; surface winds; and surface eddy diffusivity.

## Methods

The model being used for this project was originally developed and written to produce simulations of the Venus atmosphere. The code has since been reconfigured as a full-wave model that describes gravity wave propagation within the Martian atmosphere. The original model was one dimensional, in the vertical coordinate (z).

The full-wave model is based on the linearized Navier-Stokes equations and is described, for example, in Hickey et al. (1997). This model solves for linear fluctuations about an undisturbed basic atmospheric state, and returns velocity, temperature and pressure fluctuations as a function of height from the ground to the upper atmosphere (usually at least as high as 250 km altitude). Spectral 2-D and 3-D versions of the model were developed to describe mountain wave propagation over altitude and horizontal position.

After initially setting up the program, simulations will be run for various shapes. Mainly, we will be studying the shapes of large Martian mountains, such as Olympus Mons. We can compare these simulations to craters as well. The modeling for the mountain shapes will be conducted using the capabilities of the model to solve discrete Fourier transforms.

For now, basic simulations of the mean state have been plotted, as shown in Figure 1. The temperature profile was measured at varying seasons, which are represented by the ls value (where 2 is spring, 3 is summer, and 4 is fall).

## Discussion

The mean state atmosphere (with no waves present) required for the simulations was previously supplied by an early version of the Mars general circulation model used by and described by Parish et al. [2009]. We will be using output from a much newer version of this model, obtained from the Mars Climate Database Millour et al. [2018]. We have also begun testing the use of the newer wind profiles taken from this model.

We have also included the effect of CO<sub>2</sub> radiation in the model using a parameterization described by Eckermann et al. [2011]. The waves cause the atmospheric temperature to fluctuate about a mean at all altitudes. At high altitudes, the radiation from CO<sub>2</sub> becomes important, and the temperature fluctuations cause a net loss of energy from the waves. We are currently experimenting to see how important this is by comparing it to the effects of the viscosity in the model.

An interesting set of experiments that we are planning is to see how mountain wave propagation is impacted by global dust storms. We cannot model the dust, but the MCD model will provide temperature profiles and winds that are modified by dust storms (Figures 2 and 3). By using these modified mean temperature/wind profiles we can compare the mountain wave results to those obtained using the nominal profiles (no dust storms) to determine how dust storms might impact mountain wave propagation in the Martian atmosphere. This can also be compared to the mean state values.

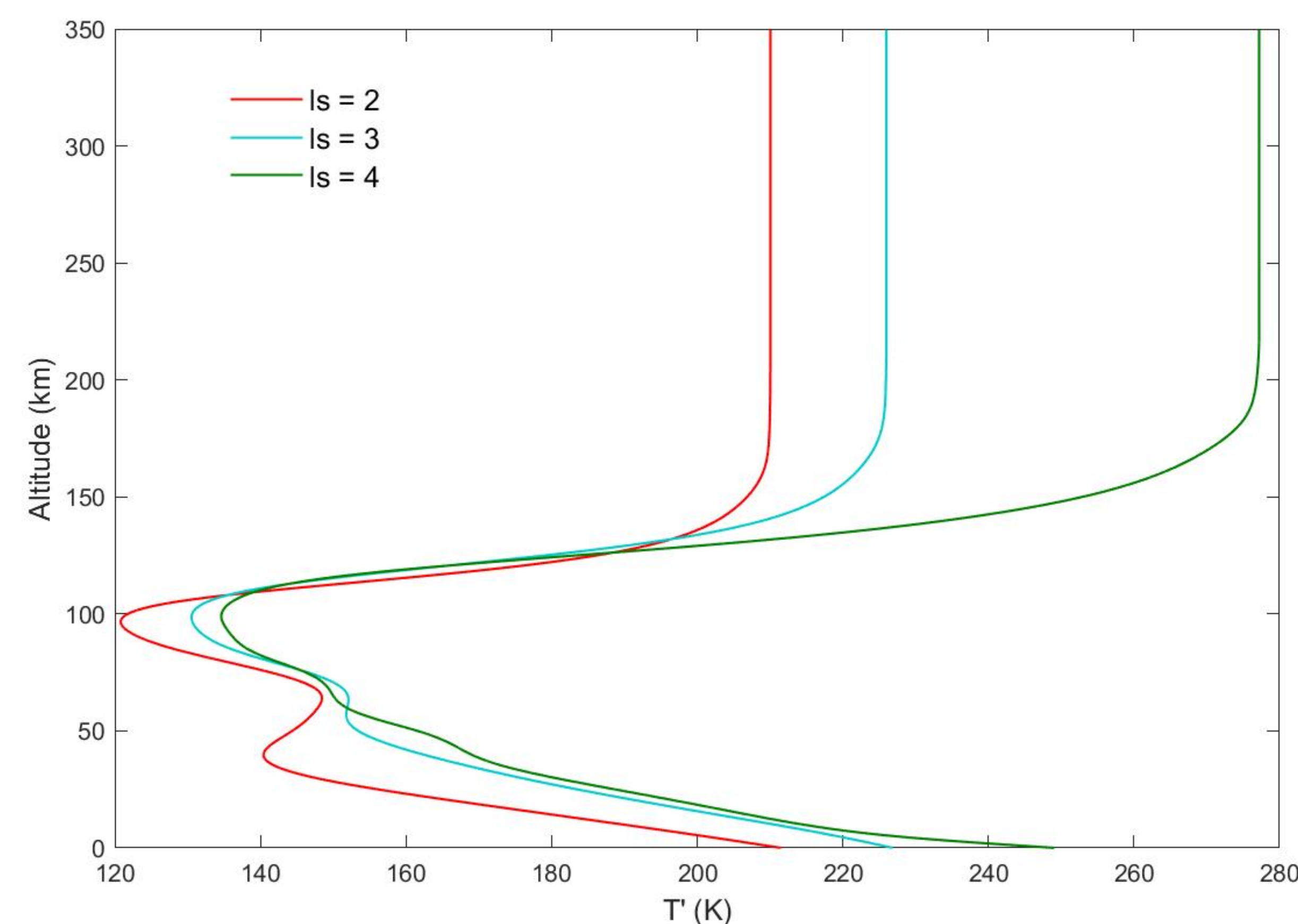


Figure 3: Simulation of mean state temperature for seasonal variations

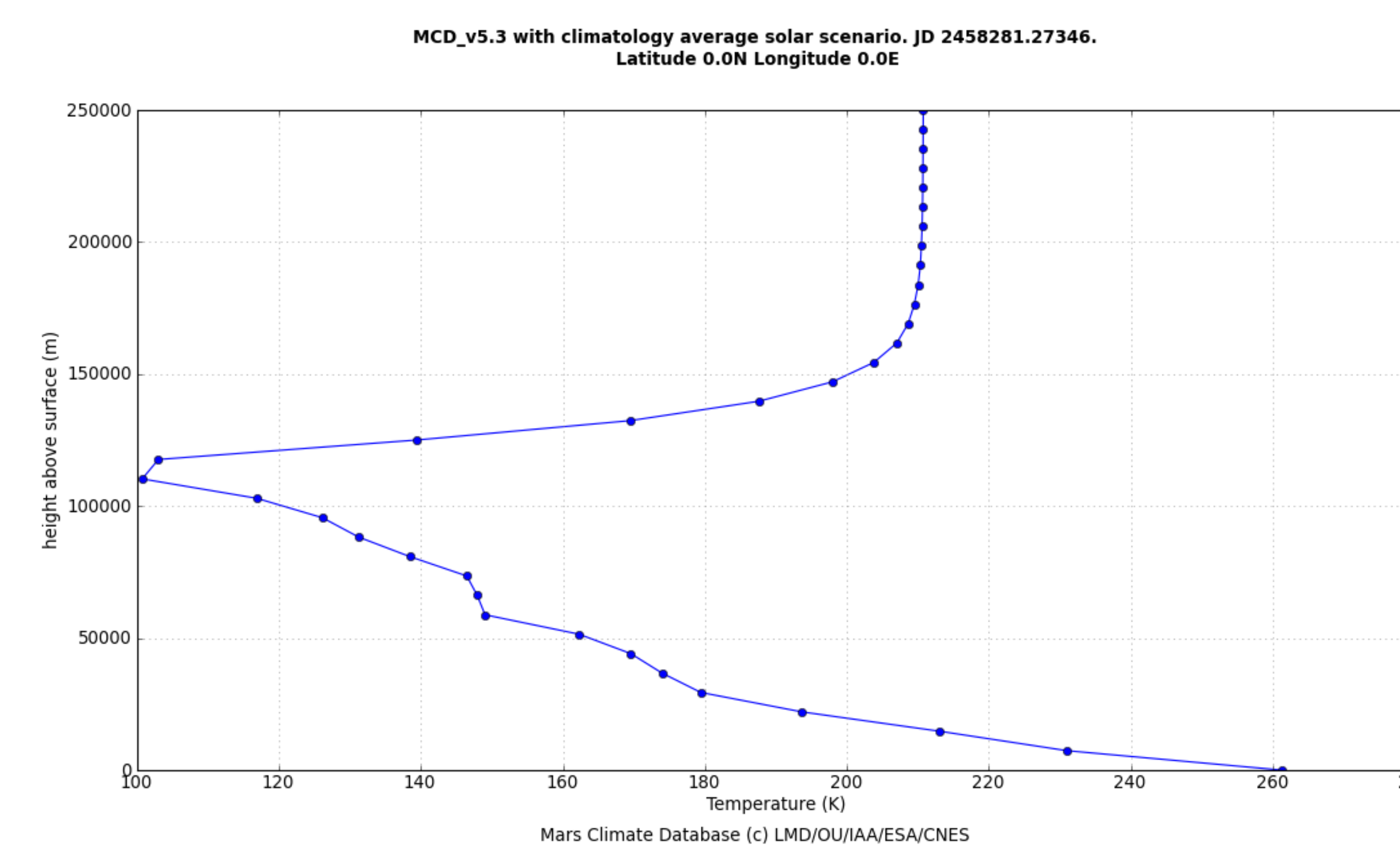


Figure 2: Simulation of global dust distribution during dust storm (June 2018) (Millour et al., 2018)

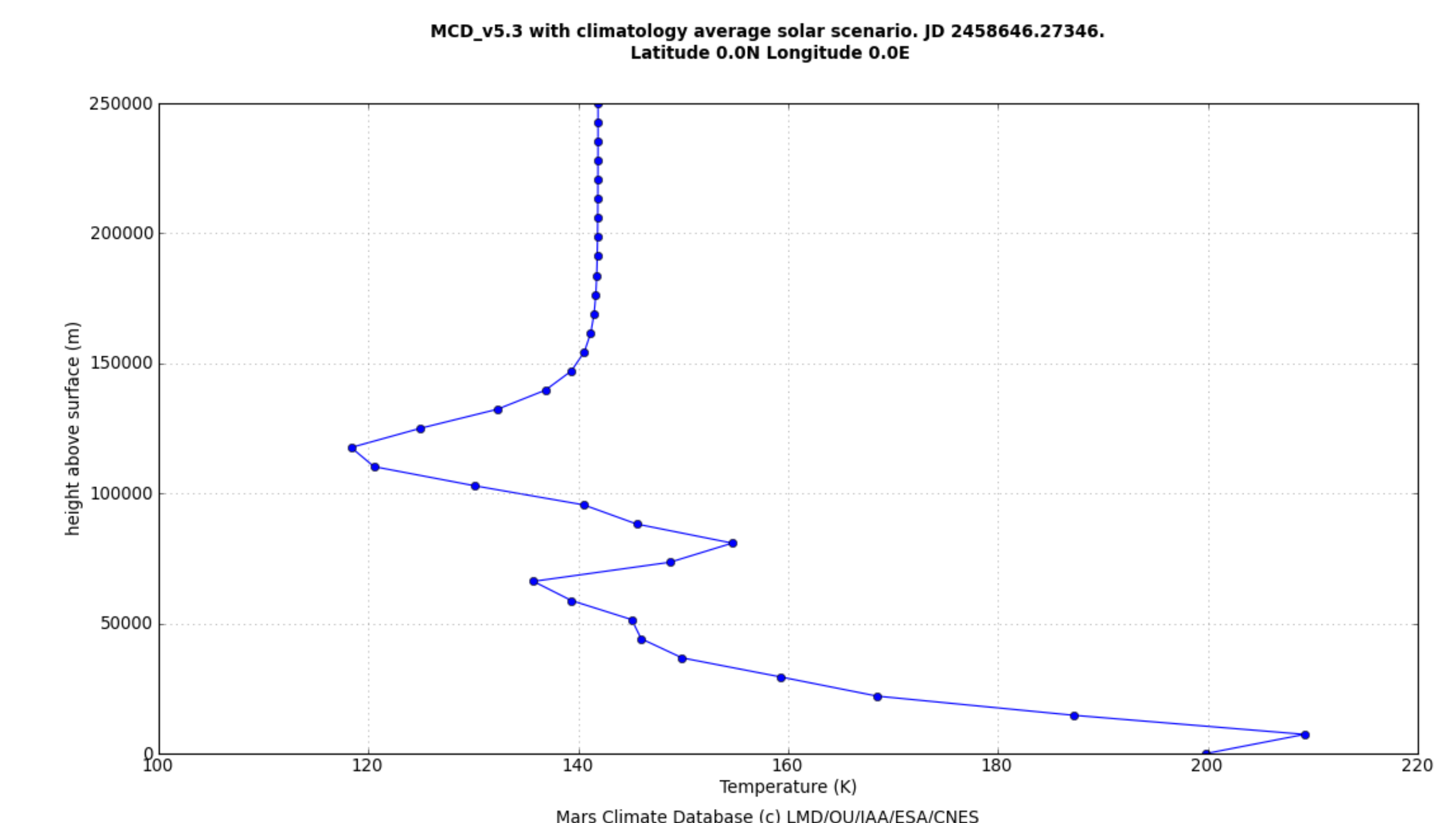


Figure 2: Simulation of global dust distribution after dust storm (June 2019) (Millour et al., 2018)

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