**Warming Ancient Mars with Water Clouds.** V. L. Hartwick¹ and O. B. Toon¹, ¹Department of Atmospheric and Ocean Sciences, Laboratory of Atmospheric and Space Physics, University of Colorado at Boulder, Boulder, CO, USA (vihai1825@colorado.edu)

**Introduction:** High clouds in the present day Mars atmosphere nucleate on interplanetary dust particles (IDPs) that burn up on entry into the Mars atmosphere. Clouds form when super-saturated water vapor condenses on suspended aerosols. The classic view of cloud nucleation on Mars considers mineral dust lofted from surface deposits as the sole source of ice nuclei. However, it is difficult to mix these aerosols to high altitudes where clouds are observed. We consider smoke particles formed from the ablation of micrometeoroids a reasonable high altitude source of ice nuclei.

Water ice clouds above 30-40 km are extremely common and are observed year round. Clouds are optically thin but can have large radiative impacts. Radiatively active water ice clouds may play a crucial role in warming the early Mars climate. Urata and Toon [1] simulate a stable warm paleo-climate for Mars if clouds form high in the atmosphere and if particles are sufficiently large (r > 10µm).

The annual fluence of micrometeoroids at Mars was larger early on in the evolution of our solar system [2]. Additionally, the water vapor budget throughout the middle and high atmosphere was likely heightened [1]. Both factors should contribute to enhanced nucleation and growth of water ice cloud particles at high altitudes. Here, we examine the radiative impact of high altitude water ice clouds on the early Mars climate and as a possible solution to the faint young sun problem for Mars.

**Model Description:** MarsCAM-CARMA is a three-dimensional general circulation model adapted for Mars from the NCAR Community Atmosphere Model (CAM3.1) in 2013 [4]. The Mars hydrological and dust cycles are extremely tightly coupled; we therefore choose to incorporate physically based, fully interactive representations for both dust lifting and advection [5] as well as cloud nucleation, growth and precipitation. Aerosol microphysics are treated in a bin-resolved sectional model (CARMA).

We consider a constant fluence of interplanetary dust particles distributed evenly at the model top. The observed altitude of peak ablation (approximately 90 km) is above our highest simulated atmospheric level; we therefore assume total ablation and recoagulation into 0.01 µm smoke particles. IDP and surface dust particles are treated as compositionally identical in simulations.

Detections by the IUVS instrument on MAVEN place a lower limit for the present day global IDP flux of 2-3 tonnes per sol [6]. For paleo-mars simulations we vary fluences from 10 to 1000 tonnes per sol.

**Results:** The addition of IDP smoke particles to the Martian high atmosphere enhances cloud formation at pressures below 100 Pa in simulations of the present day Mars climate. Figure 1 shows the zonal average ice extinction [km⁻¹] at the northern hemisphere spring equinox for SPICAM wavelengths (approximately 1.38 µm). Cloud layers are stretched vertically at all latitudes and in particular over the southern polar cap. High altitude cloud layers in simulations with IDPs are particularly notable in the northern midlatitudes near 50N.

![Figure 1: Simulated zonal average ice extinction (km⁻¹) at 1.25 µm versus pressure [Pa] for simulations with (bottom) and without (top) IDPs. Data is averaged over 2 days near Ls=180. Contour levels cover the range of 1x10⁻⁸ to 5x10⁻² with half an order of magnitude intervals.](image)

Clouds at high altitudes impact the average atmospheric thermal structure. At the same season, the addition of IDPs leads to a 3K warming at tropical high altitudes (Figure 2). Clouds can additionally indirectly impact climate by influencing large scale circulation patterns and through complex feedbacks with the global dust cycle. Similar enhancements in cloud formation...
are anticipated at high altitudes in paleoclimate simulations. These new cloud features should play an important role in the atmospheric thermal structure and may enhance surface warming. We will discuss simulations similar to those of Urata and Toon [1] exploring the ability of these clouds to solve the faint young sun problem for Mars.

Figure 2: Simulated difference in the mean temperature versus pressure for simulations with IDPs minus simulations without IDPs. Data is zonally averaged over 10 days near Ls=180. Dashed contours indicate cooling, solid contours, warming.

References: