EFFECTS OF RADIATIVELY ACTIVE CLOUDS ON WIND STRESS DUST LIFTING DURING NORTHERN HEMISPHERE SUMMER ON MARS

V. Jha , *NASA Ames, Space Science Division, Moffett field, CA, USA (vandana.jha@nasa.gov)*
M. A. Kahre, *NASA Ames, Space Science Division, Moffett field, CA, USA*

Introduction:

The Mars atmosphere has, in general, low levels of dust during the Northern Hemisphere (NH) spring and summer and increased levels during NH autumn and winter (Liu et al., 2003; Smith, 2004; Smith, 2008). In the absence of regional or global storms, dust devils and local storms maintain a background minimum dust loading during the non-dusty season. Observational surveys of dust devils suggest that they may be a major contributor to the background haze in NH spring and summer because estimations of the rate of dust lifted by dust devils are comparable to the estimated global dust deposition rates (Cantor et al., 2006; Fisher et al., 2005). Further, Mars Global Climate Model (GCM) dust cycle studies show that unresolved dust lifting processes (most often taken to be dust devils) contribute significantly to the background dust loading during northern spring and summer (Kahre et al., 2006). While it appears likely that dust devils contribute the majority of low-level dust loading during NH spring and summer, a quantitative understanding of the relative contribution of dust devils and local dust storms has not yet been achieved.

The majority of previous Mars GCM studies on dust lifting during NH spring and summer did not include the possible effects of water ice clouds on dust lifting (e.g., Newman et al., 2002; Basu et al., 2004; Kahre et al., 2006). However, radiatively active water ice clouds influence the thermal structure of the Martian atmosphere and can thus affect dust lifting through radiative-dynamic feedbacks (Wilson et al., 2008; Kahre et al., 2015). Here we present preliminary results from an investigation that focuses on the effects of radiatively active water ice clouds on dust lifting processes. This work will further our understanding of how the background atmospheric dust haze is maintained during NH spring and summer by focusing on how clouds affect local dust storm generation.

Methods:

The primary tool for this work, the NASA Ames GCM, is a 3 dimensional model that has been used for the investigation of the past and current climate of Mars (Haberle et al., 1999; Kahre et al., 2006; Kahre and Haberle, 2010; Hollingsworth and Kahre, 2010). The NASA GCM runs on an Arakawa C-grid with a normalized sigma coordinate vertical grid. A horizontal resolution of 5^o in latitude and 6^o in longitude is used for the study. The model has surface properties that include MOLA topography, and albedo and thermal inertia maps that have been derived from the Viking and Mars Global Surveyor (MGS)/Thermal Emission Spectrometer (TES) observations. The GCM has routines for representing the physics of lifting, transport and sedimentation of radiatively active dust (Kahre et al., 2006). The wind stress dust lifting parameterization from Newman et al. (2002a) is used for this study with a threshold wind stress of τ = 22.5 mN m-2. The airborne dust that interacts with solar and infrared radiation acts as ice nuclei and goes through gravitational sedimentation as free dust and as cores of water ice cloud particles. The wind-stress lifting scheme is tuned with a multiplicative ''efficiency'' factor to produce reasonable dust loadings throughout the Martian year. The microphysical processes of nucleation, growth, and settling of radiatively active water ice clouds and sublimation from the north residual cap are also included in the simulated water cycle (Montmessin et al., 2002, 2004; Nelli et al., 2009; Navarro et al., 2014). The lognormal particle size distributions of dust and cloud are represented by a spatially and temporally varying mass and number, and a constant effective variance. This method takes into account the complex processes of cloud microphysics through cloud and dust particle size evolution and is computationally efficient.

Experiments and Preliminary Results:

Three simulations that included wind stress dust lifting were executed for a period of 5 Martian years: a case that included no cloud formation, a case that included radiatively inert cloud formation, and a case that included radiatively active cloud (RAC) formation. We focus on NH spring and summer to study how radiatively active water ice clouds in the aphelion belt and in the polar hoods impact atmospheric heating and cooling, atmospheric circulation, and the pattern and magnitude of wind-stress dust lifting. Water ice clouds are known to affect atmospheric temperatures directly by absorption and emission of thermal infrared radiation. They also affect the temperatures indirectly through dynamical feedbacks. Model-predicted clouds form aloft in the tropics and subtropics (i.e., the aphelion cloud belt) and near the surface in both the northern and southern high latitudes (Polar hood clouds; Figure 1).

Water ice clouds can either radiatively warm or cool locally depending on their location, thickness, and microphysical properties (particle size, etc.). Figure 2 shows the zonal average temperature at L_s 90 for no cloud case, the radiatively active cloud case, and the difference between the two cases, respectively. As shown in Figure 2 and described in the literature, clouds in the aphelion cloud belt warm the atmosphere aloft at low latitudes (Wilson et al., 2008; Madeleine et al., 2012; Kahre et al., 2015).

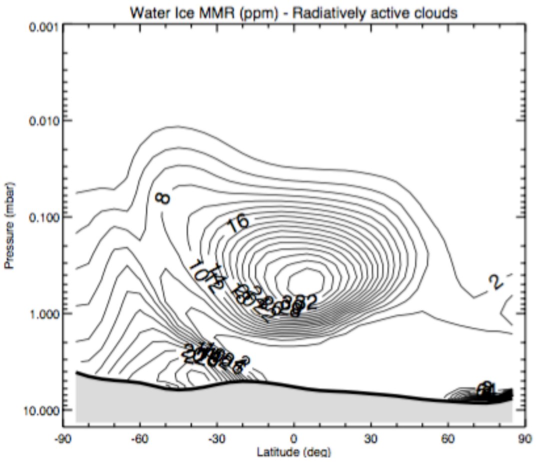

Figure 1. Zonal mean water ice mass mixing ratio (ppm) from the RAC simulation at $L_s = 90^o$.

Radiative heating by clouds in the aphelion cloud belt provides up to ~20 K warming at approximately the 0.10 hPa level in our simulation. Low-lying polar clouds radiatively cool the local atmosphere because they radiate at nearly the same temperature as the ground (Hollingsworth et al., 2011; Madeleine et al., 2012). Hence, clouds produce cooler temperatures near the surface at the poles by around 8K due to the increased loss of infrared radiation to space.

Water ice clouds also affect atmospheric temperatures through dynamical responses to radiative heating and cooling. An enhanced overturning circulation is caused by the radiative heating by the clouds in the aphelion cloud belt (Figure 3). The dynamically induced heating (~15 K at 0.5 hPa) in the south is caused by the increased overturning circulation because there is more compressional heating in the descending branch.

The dynamical response of the atmosphere to the presence of radiatively active clouds produces changes in the pattern and magnitude of surface wind stress and can thus directly affect the amount of dust injected into the atmosphere. Figure 4 shows the 10-sol mean surface stress for the simulation with no clouds, the simulation with radiatively active clouds, and the difference between the two cases at Ls = 90°. Dust lifting due to winds is caused by the momentum exchange between the atmosphere and the surface.

This is described by surface stress τ, which depends upon the wind speed and its vertical gradient, the vertical temperature gradient and air density near the surface. Regions of maximum surface winds at Ls 90 correspond to regions of maximum surface stress and thus wind stress lifting rates (Figure 4, middle panel). With and without clouds, regions of higher surface stresses include Hellas, the Northwest slope of the Tharsis, and the three longitudinal corridors of Acidalia, Arcadia and Utopia.

Slope flows in both Tharsis and Hellas produce significant dust lifting in those locations, while higher higher stresses in Acidalia, Arcadia and Utopia are produced by the concentration of the return branch of the Hadley cell into specific low-topographic longitudinal corridors. When radiatively active clouds are included in the simulation, the stronger overturning circulation produces an enhanced low-level flow in the Hadley cell return branch, which in turn produces higher surface stresses and increased dust lifting in those locations.

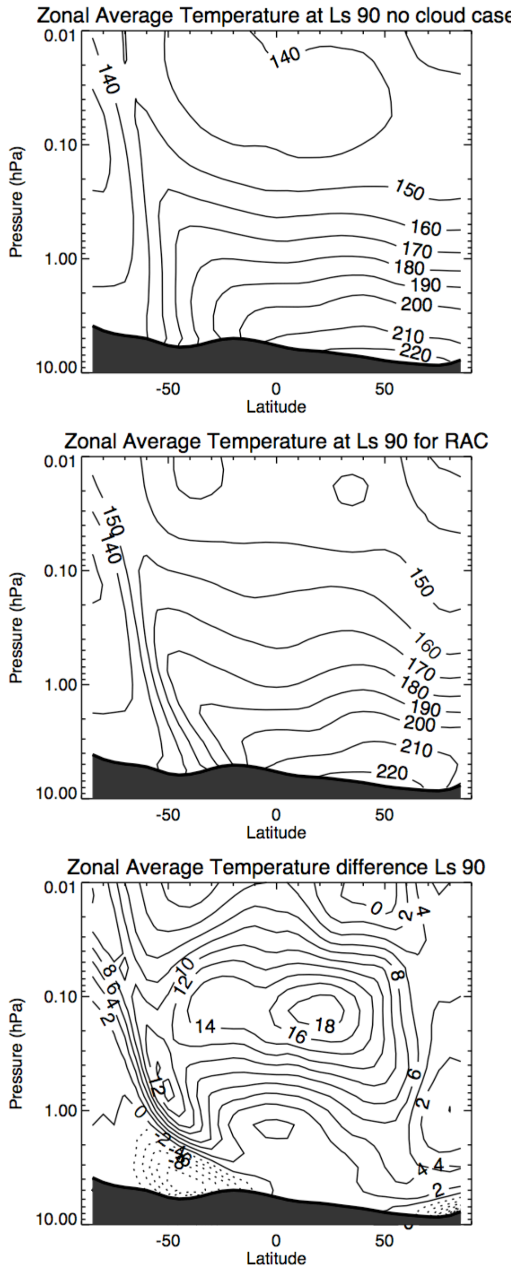

Figure 2. Zonal average temperature for the simulation with no clouds (top), for the simulation without clouds (middle) and the difference in zonal average temperature between the two cases (bottom) at $L_s = 90^o$.

Increased dust lifting Acidalia, Arcadia and Utopia leads to more dust lifting and a higher atmospheric dust loading overall than the case without cloud formation.

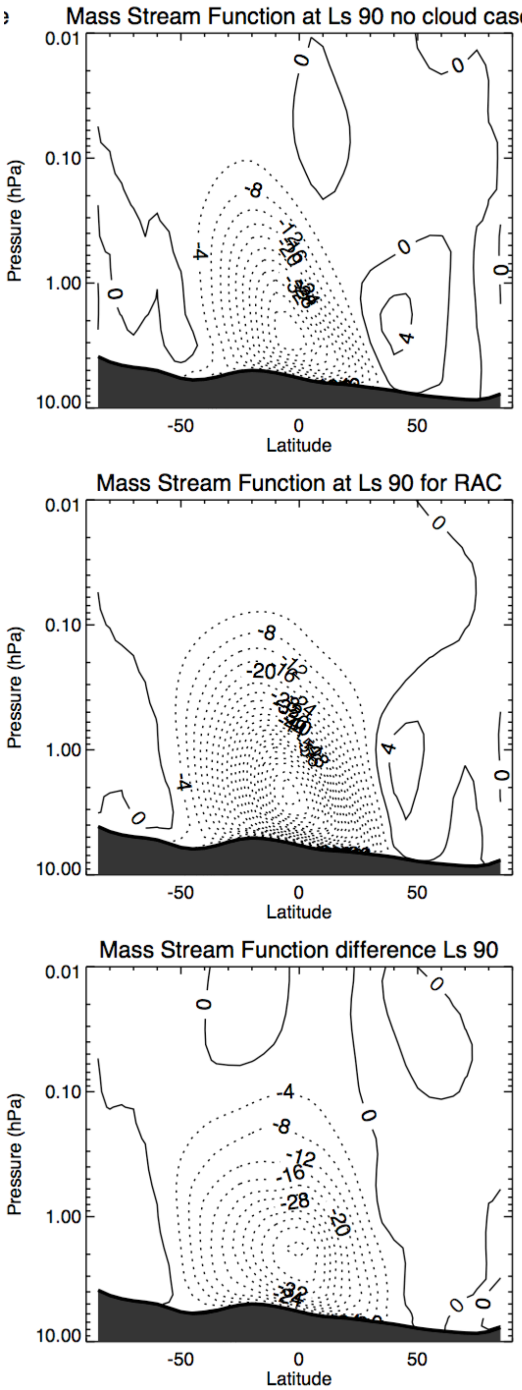

Figure 3. Mass stream function for the simulation with no clouds (top), the simulation with radiatively active clouds (middle) and the difference between the two cases (bottom) at $L_s = 90^o$.

Conclusions:

Our preliminary results suggest that with radiatively active clouds included, radiative-dynamic feedbacks generate a stronger mean overturning circulation and more pronounced wind stress dust lifting and a higher overall dust loading. These results suggest that wind stress lifting may contribute more to maintaining the background dust haze during NH spring and summer than what previous studies have shown. Further investigations need to be done to fully understand how realistic these results are. In particular, a close comparison must be made between the predicted dust storms in Acidalia, Arcadia and Utopia and the observed local storms during NH spring and summer by imagers such as MGS/MOC and MRO/MARCI.

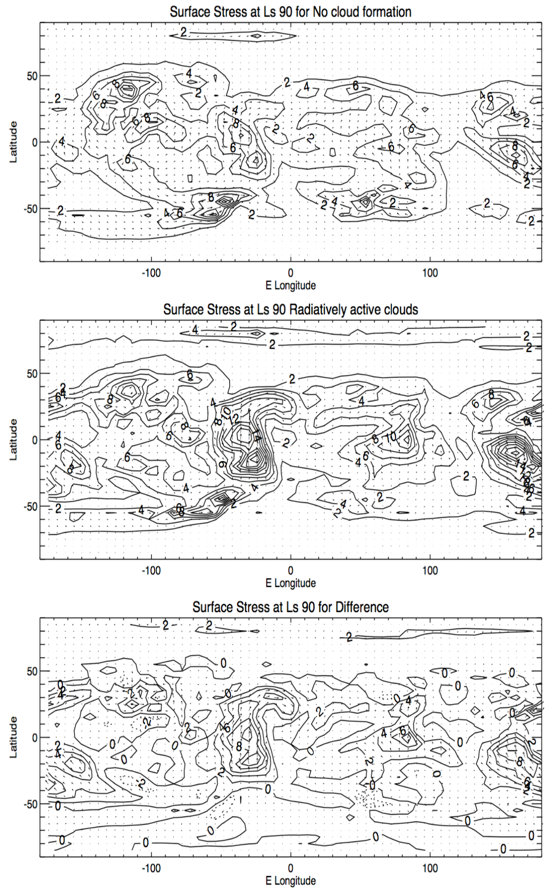

Figure 4. Surface stress for the simulation with no cloud (top), the simulation with radiatively active cloud (middle) and the difference between the two cases at $L_s = 90^o$.

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