Simulating Mars' Dust Cycle with a Mars General Circulation Model: Effects of Water Ice Cloud Formation on Dust Lifting Strength and Seasonality. M.A. Kahre (melinda.a.kahre@nasa.gov)[1], J.L. Hollingsworth[1], and R.M. Haberle[1], NASA Ames Research Center, Moffett Field, CA, 94035.

Introduction: The dust cycle is critically important for the current climate of Mars. The radiative effects of dust impact the thermal and dynamical state of the atmosphere [1,2,3]. Although dust is present in the Martian atmosphere throughout the year, the level of dustiness varies with season. The atmosphere is generally the dustiest during northern fall and winter and the least dusty during northern spring and summer [4]. Dust particles are lifted into the atmosphere by dust storms that range in size from meters to thousands of kilometers across [5]. Regional storm activity is enhanced before northern winter solstice (Ls~200°-240°), and after northern solstice (Ls~305°-340°), which produces elevated atmospheric dust loadings during these periods [5,6,7]. These pre- and post- solstice increases in dust loading are thought to be associated with transient eddy activity in the northern hemisphere with cross-equatorial transport of dust leading to enhanced dust lifting in the southern hemisphere [6].

Interactive dust cycle studies with Mars General Circulation Models (MGCMs) have included the lifting, transport, and sedimentation of radiatively active dust. Although the predicted global dust loadings from these simulations capture some aspects of the observed dust cycle, there are marked differences between the simulated and observed dust cycles [8,9,10]. Most notably, the maximum dust loading is robustly predicted by models to occur near northern winter solstice and is due to dust lifting associated with down slope flows on the flanks of the Hellas basin. Thus far, models have had difficulty simulating the observed pre- and post- solstice peaks in dust loading.

Interactive dust cycle studies typically have not included the formation of water ice clouds or their radiative effects. Cloud formation is the key process for the coupling between the dust and water cycles. Dust particles likely provide the seed nuclei for heterogeneous nucleation of water ice clouds [11,12]. As ice coats atmospheric dust grains, the newly formed cloud particles exhibit different physical and radiative characteristics. As the ratio of ice-to-dust increases, the particle's scattering properties become those of ice instead of dust. The mass and size (and therefore bulk density) of the cloud particles depend on the fraction of ice versus dust. Because the gravitational fall velocity of particles depends on these quantities, cloud formation will either increase or decrease the suspension lifetime of atmospheric dust. ***The coupling between the dust and water cycles likely affects the atmospheric distributions of dust, water vapor and water ice and thus atmospheric heating and cooling and the resulting dynamics (Figure 1).***

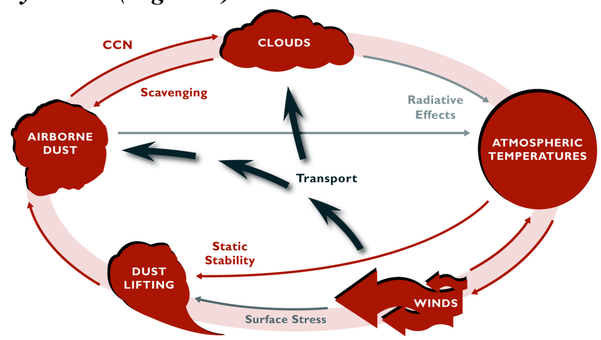

Figure 1: Coupling processes between the dust and water cycles, and the dynamics of the atmosphere.

Our goal is to investigate the effects of fully coupling the dust and water cycles on the dust cycle. We show that including water ice clouds and their radiative effects greatly affect the magnitude, spatial extent and seasonality of dust lifting and the season of maximum atmospheric dust loading.

Methods: We use the NASA Ames Mars GCM (version 2.1d) for this investigation. A fully interactive dust cycle is implemented, which includes the lifting, transport and removal of radiatively active dust [8]. Dust is lifted from the surface when the momentum imparted to the surface (characterized as the surface wind stress, τ) exceeds a critical value, $\tau^* = 22.5$ mN m^{-2}. Airborne dust interacts with solar and infrared radiation, provides seed nuclei for water ice clouds, and undergoes gravitational sedimentation as free dust and as cores of water ice cloud particles. A complete water cycle is included that contains sublimation from the north residual cap and the microphysical processes of nucleation, growth, and settling of water ice clouds [11,13]. Two model simulations were carried out for this investigation: one with the dust cycle only (i.e., no cloud formation) and one with fully coupled dust and water cycles. These simulations were designed to explore the sensitivity of the dust cycle to cloud formation and their radiative effects.

Results: Simulated results indicate that including the couplings between the dust and water cycles greatly affect the predicted dust cycle (Figure 1). An increased level of dustiness is maintained throughout northern spring and summer, caused by wind stress lifting along the receding north seasonal cap and in the tropics. During northern autumn and winter, the global dust loading exhibits two distinct maxima, one centered at Ls~210° and one centered at Ls~270°. Rigorous wind stress lifting at high northern latitudes before the north seasonal CO_2 cap starts to grow and along the south receding seasonal CO_2 cap causes the pre-solstice peak. We focus on the Ls 210° season to understand what processes are important for producing the early dust loading peak in the fully coupled simulation.

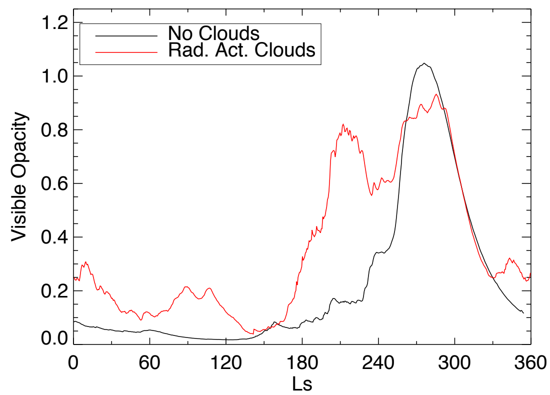

Figure 2: Globally averaged dust opacity for the no-cloud case (black) and the radiatively active cloud case (red).

The thermal structure of the atmosphere is greatly influenced by the presence of radiatively active water ice clouds at L_s~210°. Compared to the no-cloud case, when the radiative effects of water ice clouds are included the predicted temperatures agree better with observations [14]. The atmosphere is warmer in the tropics but cooler near the surface in the polar regions. These effects are due to a combination of the direct radiative effects of clouds and the increased dust loading that is present in this simulation.

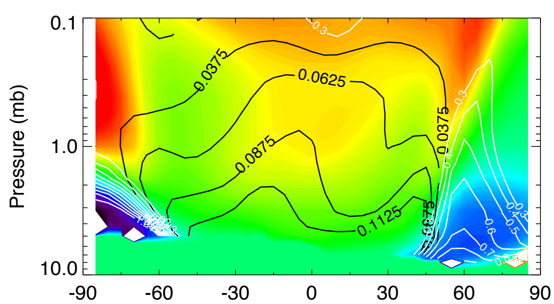

Figure 3: Zonally averaged difference (radiatively active case minus no-cloud case) in temperature (color fill ranging from +35 K, red, to -35 K, purple), dust opacity (black contours), and cloud opacity (white contours).

The combined effect of warming at low latitudes and cooling at high latitudes is to make the atmosphere in the middle northern latitudes more isothermal and to tighten the equator-to-pole thermal gradient (i.e., the baroclinicity of the atmosphere). The increased baroclinicity supports more rigorous transient eddies, which causes an increase in the likelihood that the surface stress exceeds the threshold for lifting. Thus, dust lifting is strengthened at high northern latitudes, which leads to the global opacity peak at this pre-solstice season. A positive feedback loop is therefore hypothesized between dust lifting, cloud formation and transient eddy amplification. The relationship of these processes is depicted in Figure 4.

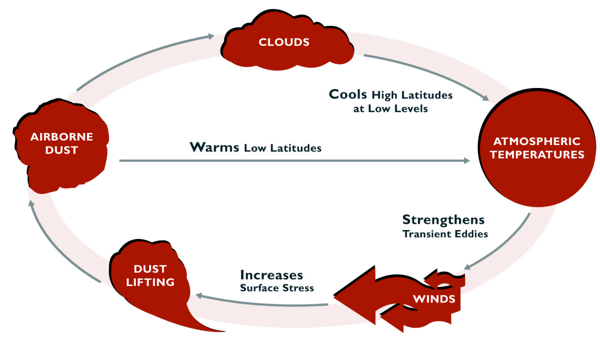

Figure 4: Hypothesized feedbacks between dust lifting, cloud formation and transient eddy amplification.

Preliminary Conclusions: Fully coupled dust and water cycle simulations show that clouds significantly affect the simulated dust cycle. Additionally, coupling the dust and water cycles lead to improvements in some aspects of the simulated dust cycle. Most interestingly, increased eddy activity at L_s 180-240° increases the vigor and spatial extent of dust lifting in the northern hemisphere. This increased dust lifting produces a peak in global opacity at a season that is more consistent with TES observations during non-global dust storm years than the simulations that do not include clouds and their radiative effects. Because of the effects of coupling the dust and water cycles discussed here, it is very likely that these couplings are vital to the simulation of the dust cycle.

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