Transient Eddies in the Atmosphere of Mars: The Crucial Importance of Water Clouds. J. R. Barnes[1], M. S. Rucker[1], and D. Tyler, Jr[1]., [1]College of Earth, Ocean, and Atmospheric Sciences, Oregon State University, Corvallis, OR, 97331, barnes@coas.oregonstate.edu.

Introduction: It has recently become clear that the radiative effects of water ice clouds in the atmosphere of Mars are very important for its thermal structure [1,2,3,4]. Given the magnitude of the thermal effects found in modeling studies, water clouds are also of considerable importance for the atmospheric circulation. The polar hood clouds that cover the seasonal polar caps during the wintertime seasons produce strong cooling at relatively lower levels in the polar atmosphere. Coupled with substantial heating due to water clouds at higher levels at lower latitudes, the middle latitude baroclinicity of the wintertime atmosphere is increased by the radiative heating and cooling due to the water clouds. This should intensify the transient eddies that feed on the baroclinicity of the wintertime atmosphere. Several recent preliminary GCM studies that incorporated the radiative effects of water clouds (RAC) showed that this was indeed the case [2,4]. These results have motivated us to carry out much more detailed studies with a Mars GCM. We have intentionally made use of GCM simulations in which the water cycle is fairly dry in comparison to observations. This is because the GCM that we are using (a modified version of the NASA-Ames GCM) tends to produce overly thick and extensive polar hood clouds during wintertime. If the water cycle is allowed to be as wet as the observations show, then the polar clouds become much too thick and extensive in the model. The radiative effects due to the model clouds would thus be considerably different from those produced by the observed polar hoods.

The Model: We have made use of a modified version of the current NASA-Ames Mars GCM [1,2]. This is a state-of-the-art GCM for Mars that includes a full water cycle with clouds that can be radiatively active. The model is generally run with annual dust scenarios that are based very closely on the TES data. Our version of this GCM has significantly higher vertical resolution than the standard Ames model, with 40 layers and a higher model top. The transient eddies can have very shallow vertical structures, making high vertical resolution in the lower part of the atmosphere very important. We have also modified the Ames GCM to insure that the edges of the seasonal polar caps are located quite close to where they should be according to observations, as a function of season. This has been accomplished through the implementation of a relatively simple scheme that acts to "nudge" the cap edges towards their observed locations continuously over the annual cycle. Over extended model simulations (typically 11 Mars years) the cap edges adjust to be in very good agreement with the observations as a function of season. The location of the cap edges is extremely important in determining the location and extent of the polar hood clouds. If the cap edges in the GCM do not agree well with the observations, the polar hood clouds will not agree well with the observations. It has become standard practice to tune Mars GCM's to the Viking annual pressure cycles. The problem in doing (only) this is that it does not insure that the locations of the seasonal cap edges will agree well with observations throughout the annual cycle. This is simply because the depth of the CO_2 ice in the seasonal caps in the model, as a function of latitude, can differ greatly from reality. The NASA-Ames GCM has previously been tuned to agree extremely well with the Viking pressure observations, so constraining the polar cap edges to agree with observations pulls the model pressure cycle out of agreement with the Viking data. The resulting disagreement with the Viking annual pressure cycle is small, however, and is thus of no real significance for the atmospheric thermal state and circulation. The location of the polar cap edges is extremely important for the polar hoods, and for the atmospheric thermal state and circulation.

Results: The results that we have obtained to date show that RAC effects are extremely important for various aspects of the wintertime transient eddy activity in the GCM simulations. As several previous studies have shown the eddy activity is substantially stronger with RAC [2,4]. The total eddy temperature variance with RAC in the GCM is roughly a factor of two larger than that without RAC. RAC effects act to produce very dramatic changes in the meridional structure of the eddy activity as a function of season, especially in the northern hemisphere. The transient eddy activity extends much further equatorward in the north during early autumn. Without RAC effects the early autumn eddy activity is located much too far poleward in comparison to that observed by TES. During northern springtime the strongest eddy activity (in temperature) very closely follows the retreating cap edge with RAC, and this activity can be extremely strong. This makes what was already a major puzzle in the comparison of model results to the TES observations even more of a puzzle. Analyses of the

TES data have found that the transient eddy activity during northern springtime is not particularly strong. One possible reason for this is thus that the transient eddies in the GCM in northern springtime have very shallow vertical structures, and this would have made such eddies very difficult for the TES instrument to have "seen".

Perhaps most interestingly, RAC effects in the GCM act to dramatically alter the distribution of the eddy activity in zonal wavenumber. In particular, RAC effects act to greatly increase the strength of the eddy activity at zonal wavenumber 3, especially in the northern hemisphere. RAC causes the variance at wavenumber 3 to increase by factors of ~ 4-5 and greater. RAC effects can cause wavenumber 3 to become the dominant transient wavenumber (in temperature variance) during certain seasonal periods; it is never very close to being dominant in the north without RAC effects. Studies of flushing dust storm activity in the northern hemisphere during early autumn and late winter [e.g., 5,6] have shown that wavenumber 3 disturbances with short periods (~ 2-2.5 sols) play a crucial role in producing many of these storms – some of which then evolve into large regional storms in the southern hemisphere. It is now very clear that local dust storms associated with the transient eddies in the northern hemisphere are extremely important in the annual dust cycle of Mars, as they act to strongly increase the atmospheric dust loading in early autumn and late winter. In a recent GCM modeling study the possible role of dust in enhancing the wavenumber 3 eddies in the north was investigated [7]. The results of our studies show that RAC has a very strong preferential effect on the amplitude of wavenumber 3 in the north, such that one does not need to appeal to dust distributions that are largely at odds with the observational data. This does not mean that the dust distribution is not also of considerable importance, but it does not appear to be the primary factor which is responsible for the existence of very strong wavenumber 3 eddies in the northern hemisphere of Mars, in both early autumn and late winter periods. The polar hoods are always present in these seasons and their distributions are relatively well established by observational data. Despite this, we very much need better observation data for the polar hood clouds in view of their importance for the transient eddies and other components of the circulation. As noted, the NASA-Ames GCM does not do a very good job of simulating the polar hood clouds – as they become much too extensive and thick when the water vapor cycle is in very good agreement with observations. This indicates that some aspects of the microphysical processes in the GCM are not in very good accord with what is happening in the atmosphere of Mars over the seasonal polar caps during wintertime. Recent mesoscale modeling studies of the northern polar region during summer that we have carried out indicate that the fraction of dust particles that act as ice nuclei in the clouds may be extremely low, on the order of ~ 5-10% [8].

In summary, detailed ongoing studies with a modified version of the NASA-Ames GCM have shown that RAC effects are of crucial importance for transient eddies in the Martian atmosphere. The RAC effects strongly intensify the overall transient eddy activity, they dramatically alter the latitudinal distribution of eddy activity as a function of season (especially in the north), and they change the wavenumber distribution of eddy activity (especially in the north). RAC also alters the dominant periods of the transient eddies, tending to make these shorter. RAC effects appear to be critical to the existence of very strong wavenumber 3 eddy disturbances during early autumn and late winter in the northern hemisphere. These wavenumber 3 disturbances have been shown to play crucial roles in producing many of the flushing dust storms that occur during these two seasonal periods. It thus appears that RAC effects are of crucial importance for realistic GCM simulations of the flushing dust storms, and the annual dust cycle on Mars.

Improved data for the polar hood clouds is very much needed in order to better constrain the model clouds and RAC effects. The seasonally varying atmospheric dust loading is also of very considerable importance for the transient eddies. Much better data constraints on this are needed at higher latitudes during the wintertime seasons. Finally, it is virtually certain that at least some of the very complex wintertime seasonal variability that observations have revealed is the result of coupled interactions between dust, water vapor, water clouds, radiation, and dynamics in the Martian atmosphere. This will be extremely challenging to simulate well with models, and will require greatly improved models as well as better and more extensive observational data.

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