THE ROLE OF THE NORTH RESIDUAL CAP IN THE PRESENT MARS WATER CYCLE.
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Introduction: General Circulation Models have been moderately successful in simulating the Martian seasonal water cycle as observed by the Viking MAWD and MGS TES experiments [1,2,3]. The models generally assume that the north residual cap (NRC) is the only permanent exchangeable reservoir for atmospheric water vapor. Recently, Fouchet et al. [4] present results of the Mars Express PFS/LW observations that show a much drier water cycle than seen by MAWD or TES - by a factor of 1.5 - and have suggested that at least the TES data are biased high due to resolution and line strength issues with the weak band retrievals. Apparently this seems to be the case [5]. When they correct for this bias, the two data sets agree. The SPICAM and OMEGA instruments on Mars Express also give generally lower water columns than observed by TES or Viking, though these retrievals are subject to more complications (see discussion in [4]).

If TES data are biased high, this leaves the Viking data set as the only "wet" data set and raises the possibility for genuine interannual variability. However, it might be premature to pursue this possibility until all the issues associated with these retrievals are fully sorted out. What can be done, however, is to begin a systematic investigation into how one can get the models to dry out the water cycle to the level observed by Mars Express and corrected TES. There are several possibilities: include an adsorbing regolith [1,6,7]; increase cloud particle sizes [1], reduce sublimation from the NRC [this work]; or some combination of all three.

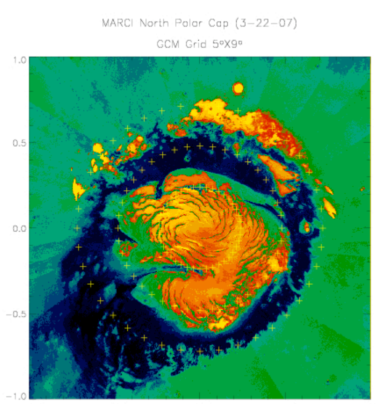

Fig. 1. False color MARCI image of the NRC with GCM grid points at 5° lat by 9° long resolution overlaid (+).

Here we explore the role of the NRC in controlling the present water cycle. Our motivation is based on the fact that the models represent the NRC as a homogeneous ice sheet poleward of a given latitude, nominally 80°N, depending on resolution. Fig. 1 shows that such an assumption grossly overestimates the amount of polar ice and thus the models may be overestimating the amount of water the NRC actually supplies the atmosphere during summer.

Ames GCM v. 2.1: We simulate the present water cycle on Mars using the Ames Mars General Circulation Model (GCM) version 2.1. This version runs with our new radiation code (2-stream model with correlated k's), and a cloud microphysics scheme that assumes a log-normal particle size distribution whose first two moments are carried as tracers, and which includes nucleation, growth, and settling of ice crystals. Atmospheric dust is partially interactive in the present simulations. The radiation code sees a prescribed distribution that follows the TES year one observations with a vertical variation that is seasonally dependent. The cloud microphysics code interacts with a transported dust tracer column whose surface source is adjusted to maintain the TES distribution. In these simulations the clouds are radiatively inactive. For the present work, we run with a horizontal resolution of 5° latitude and 9° longitude. There are 24 vertical layers increasing in thickness with altitude with the topmost layer at ~ 80 km. The model is run from an initially dry state with a prescribed NRC providing the only source of atmospheric water vapor. A seasonally repeatable cycle is obtained in 5 Mars years.

Results: We have conducted three simulations. A baseline simulation with the NRC boundary at 80°N, a "small cap" simulation with the NRC boundary at 85°N, and a "reduced sublimation" simulation with the NRC boundary at 80°N, but with the sublimation reduced to 60% of the computed value. For the meeting in July, we hope to have completed a higher resolution simulation (5° lat by 6° long) with the NRC incorporated into the model as illustrated in Fig. 1.

Table 1 lists the hemispheric annual mean abundances for each of these simulations. The PFS/LW abundances are estimated by dividing TES by 1.5 since the PFS/LW coverage is not global.

Table 1. Annual mean water abundances (10^{12} kg)

Run	NH	SH	Total
TES	1.14	0.70	1.85
PFS/LW	0.76	0.47	1.23
Baseline	1.18	0.61	1.79
Small Cap	0.54	0.31	0.85
Red. Subl.	1.05	0.56	1.61

Fig. 2 displays the zonal mean column water abundances. The baseline simulation produces a water cycle similar to that seen by Viking and TES with maximum water abundances of ~ 110 pr-μm at high latitudes during summer. The annually averaged water abundances for the northern and southern hemispheres are also similar to that seen by TES.

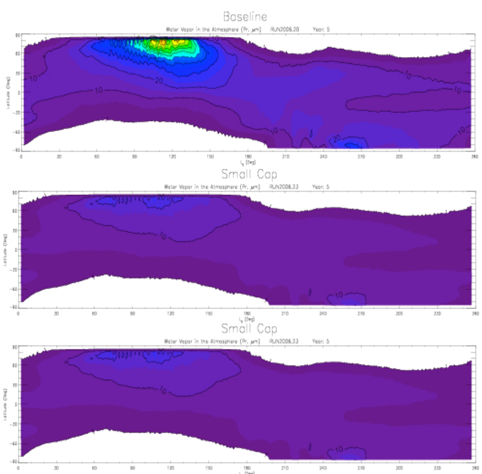

Fig. 2. Zonal mean column abundances of atmospheric water vapor (pr-μm).

There are some discrepancies. As shown in Fig. 3 the baseline model is too wet during northern summer and too dry during southern summer. The excess during northern summer could easily be the result of our assumption that ice exists everywhere poleward 80°N. Indeed the small cap simulation shows that the water cycle dries out by more than a factor of 2 when moving the boundary 5° further north. Furthermore, the mass budget of the NRC in the baseline simulation indicates that the cap is not stable; over time there would be a net transfer of water from the 80°N latitude grids to the 85°N latitude grids.

The dryness during southern summer is a robust result in all our 5°x9° simulations and is mostly a reflection of a dry southern hemisphere. Since the source of southern hemisphere water is the sublimation of the seasonal ice deposits that are incorporated into the south CO_2 ice cap during northern summer (southern winter), this could indicate that the model is underestimating the north to south transport during northern summer. It could also indicate that the model is missing a source of water in the southern hemisphere subsurface. However, preliminary simulations with a higher resolution run (5°x6°) shows a wetter atmosphere during southern summer indicating that higher resolution does lead to enhanced transport.

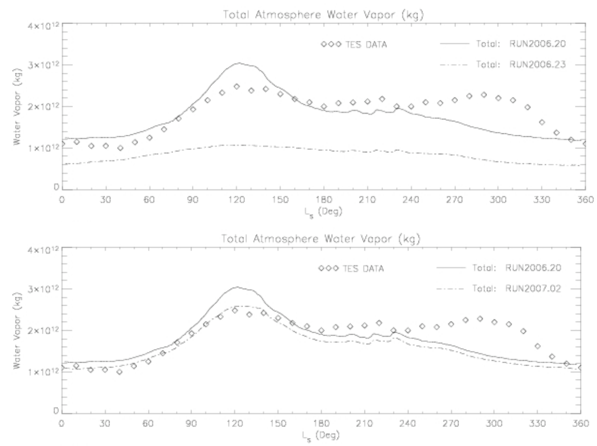

Fig. 3. Seasonal variation of the global water abundance for TOP: the baseline (solid) and small cap (dashed) simulation and BOTTOM: the baseline (solid) and reduced sublimation simulation (dashed). TES observations are solid circles.

Reducing the sublimation flux of the NRC by 60% of the baseline simulation does dry out the water cycle, but not by the same percentage. The global annual mean water content of the atmosphere decreases only about 10%. The main effect is to reduce the northern hemisphere peak summertime abundances from ~110 pr-μm to ~80 pr-μm. This result may be due to a negative feedback in the system. Reducing the sublimation flux leads to lower humidities which leads to higher moisture fluxes since sublimation is proportional to the near-surface humidity gradient.

Discussion: These results suggest that it is the size of the NRC that models must pay close attention to. Bottger [8] reached a similar conclusion. A preliminary estimate of the fraction of ice poleward of 80°N shown in Fig. 1 indicates that only 53% of the area is covered with material with an albedo higher than the bare ground.

Another factor is the temperature of the cap. The sublimation flux is very sensitive to the temperature of the NRC, which can ultimately control the global steady-state moisture abundances [2]. Fig. 4 shows a comparison of NRC temperatures simulated by our model and those observed by TES. Overall, the agreement is fair. However, given the nonlinear dependence of sublimation on temperature the differences can be significant. In general, the model is too warm early on, and too cold for most of the season. When averaged over the summer season, the model is cold with respect to TES, which suggests that we are underestimating the total flux of water into the atmosphere.

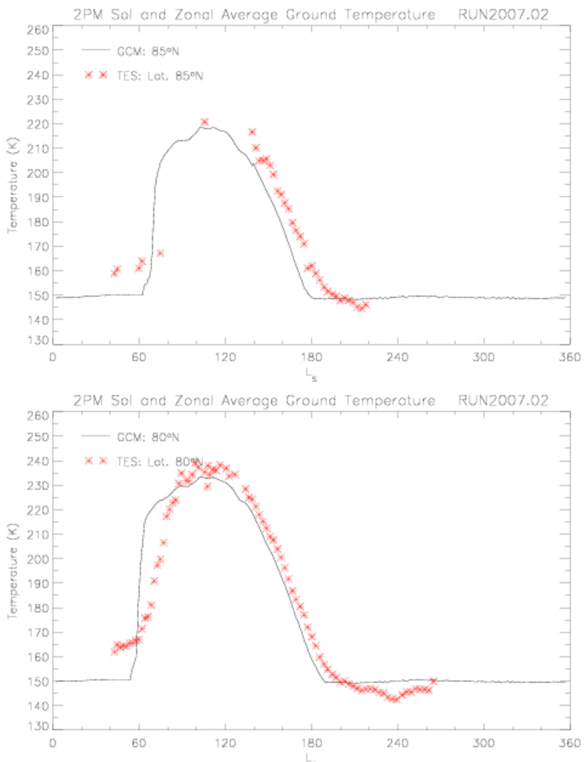

Fig. 4. Sol and zonal averaged surface temperatures at 85°N (top) and 80°N bottom. Solid lines are GCM temperatures red asterisks are TES observations.

Conclusion: The PFS/LW observations and the apparent bias of TES water column abundances on the high side suggest that the Martian water cycle during the past decade is drier than seen by Viking. The presents a problem for models of the water cycle that have successfully reproduced the major features of the Viking and uncorrected TES data sets. Specifically, they must find ways to dry out the water cycle by about a factor of 1.5.

In this work we have explored one possibility. Namely, shrinking the size of the NRC. Our baseline model assumes a cap size that is far bigger than actually observed. And when its size is reduced by a single grid point in latitude (5°), it dries out the water cycle too much thus indicating the importance of cap size. However, we have also shown that on average our simulated temperatures are too cold with respect to TES, which tends to mitigate the size problem. Ultimately what is needed is a simulation with sufficient resolution to faithfully represent the observed distribution of ground ice within the NRC cap, and which also reproduces this observed cap temperatures. Only then will we have some confidence in assessing the role the NRC cap plays in the current water cycle.

References: [1] Richardson M.I. and Wilson R.J. (2002) *JGR, 107,* 5031-5063. [2] Richardson M.I. et al. (2002) *JGR 107*, 5064-5099. [3] Montmessin F. et al. (2004) JGR, 109, E10. [4] Fouchet T. et al. (2007) *Icarus*, in press. [5] Michael Smith, personal communication. [6] Houben, H. et al. (1997) *JGR 102*, 9069-9083. [7] Bottger, H.M., et al. (2005), *Icarus 177*, 174-179. [8] Bottger, H.M. Ph.D. Thesis, Oxford University (2003).