WATER ICE CLOUD FEEDBACKS OVER THE NORTH POLAR RESIDUAL CAP AT MODERATE OBLIQUITY. M. A. Kahre[1] (melinda.a.kahre@nasa.gov) and R. M. Haberle[1] (robert.m.haberle@nasa.gov), [1]NASA Ames Research Center, MS 245-3, Moffett Field, CA, 94035.

Introduction: Several global climate modeling studies have now shown that water ice clouds can warm the surface 10s of K at moderate obliquities [1,2,3]. Significant greenhouse warming occurs because the predicted clouds are optically thick, the cloud particles are large enough to efficiently interact with infrared radiation, and the clouds either form at or are transported to high altitudes where the atmosphere is cold. Radiative-dynamic feedbacks play a critical role in producing the conditions needed for a strong cloud greenhouse. Two feedbacks have been identified: one involves atmospheric warming by clouds aloft at lower latitudes. These clouds are generally associated with the global Hadley circulation. The second feedback involves clouds that form over the North Polar Residual Cap (NPRC) during summer. These clouds are more closely associated with the regional polar circulation. We focus here on the second of these feedbacks with the goal of understanding the details of the interactions between sublimation, cloud formation and transport in the north polar region. We show that these feedbacks strongly control the wetness of the atmosphere and the strength of the cloud greenhouse at moderate obliquity.

Methods: We use the NASA Ames Legacy Mars Global Climate Model [4], which is supported by the Agency's Mars Climate Modeling Center, to investigate radiative-dynamic feedbacks by water ice clouds in the north polar region at moderate obliquity. We present two simulations at 30° obliquity: one with radiatively active clouds and one with radiatively inert clouds. With the exception of modifying the obliquity, the version of the model used here is identical to that presented in [4]. We note that the dust forcing in both of these simulations is based on observations from MY 24 [5]. In these simulations, permanent ice reservoirs do not form outside of the north polar region, indicating that the North Polar Residual Cap (NPRC) is stable and the water cycle is closed.

Results and Discussion: As summarized in Table 1, clouds significantly impact the climate at 30° obliquity. While radiatively active clouds increase the planetary albedo over the case with inert clouds, they also increase the annual mean surface temperature by 15 K.

	A_p	T_e (K)	T_{se} (K)	T_e-T_{se} (K)	T_g (K)
Active	0.34	202	226	24	219
Inert	0.26	208	216	8	204
A-1	.08	-6	10	16	15

Table 1: Planetary Albedo (A_p), effective temperature at the top of the atmosphere (T_e), effective surface temperature, greenhouse power (T_e-T_{se}), and surface temperature (T_g) for the case with radiatively active clouds and the case with radiatively inert clouds.

During NH summer, the radiatively active cloud case produces clouds that grow thick, warm the surface, and enhance sublimation relative to the simulation with radiatively inert clouds (Figure 1). This occurs because clouds extend to high altitudes over the NPRC (Figure 2) and radiate to space at a cold temperature, forcing the surface to warm. The sublimation flux increases due to the warmer surface, which in turn increases the wetness and the cloudiness of the polar atmosphere. Feedbacks with the circulation in the polar region help transport vapor and clouds up high (not shown).

It is notable that the strongly positive feedback between cloud formation and sublimation results in a significantly wetter and cloudier atmosphere (Figure 3), which in turn drives a strong cloud greenhouse. The atmosphere nearly an order of magnitude wetter due to radiative-dynamic feedbacks associated with water ice clouds.

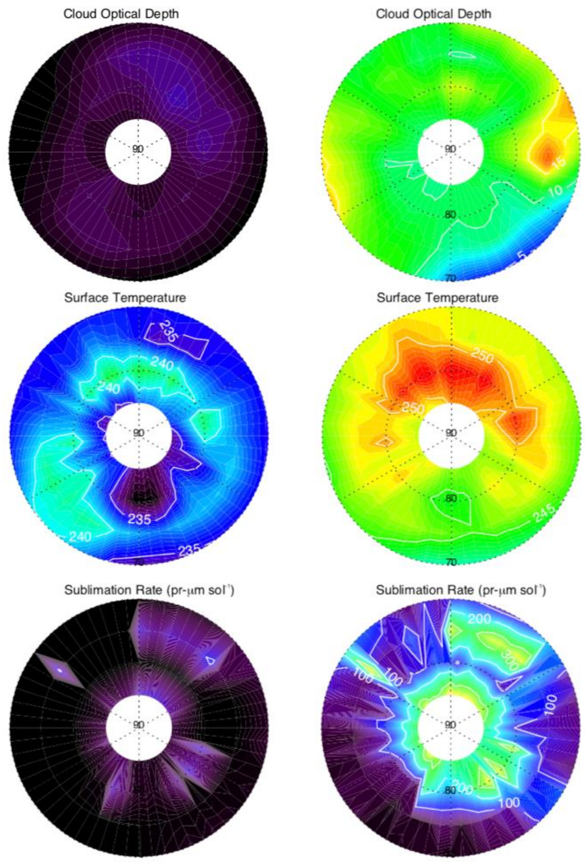

Figure 1: North polar 10-sol average cloud optical depths (top panels), surface temperatures (middle panels) and sublimation rates (bottom panels) at L_s 90 for the inert cloud case (left panels) and the radiatively active cloud case (right panels).

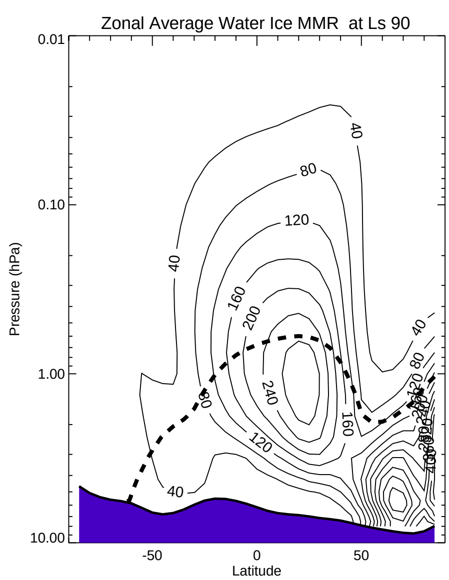

Figure 2: 10-sol zonal average water ice cloud mass mixing ratio (10^{-6} kg kg^{-1}) at L_s 90. The dashed line denotes where the cumulative top-down optical depth is unity.

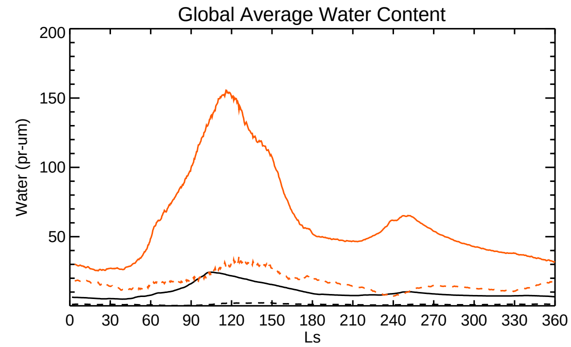

Figure 3: Global mean water vapor (solid lines) and water ice (dashed lines) for the case with radiatively active clouds (orange lines) and the case with radiatively inert clouds (black lines).

Summary and Conclusions: We have drawn attention to the clouds that form over the north residual cap during summer and their importance to the character of the water cycle. In our simulations they warm the surface and increase the water sublimation rates, which enhances the cloudiness over the cap and changes the circulation and the transport of water from the high latitudes. This strongly positive feedback significantly increases the cloudiness of the atmosphere and thus the effectiveness of the cloud greenhouse. A key aspect of this feedback is the ability of the polar circulation to transport moisture to high altitudes. A preliminary analysis of our model suggests that the regional polar circulation is complicated and that several of its components are involved. This highlights the importance of realistically simulating clouds over the NPRC, which has been challenging for modeling groups for current day Mars. Future modeling efforts will involve utilizing the NOAA/GFDL cubed-sphere dynamical core, which will allow for higher resolution simulations with a grid that does not have the converging meridian problem that all latitude/longitude grids exhibit. This should allow us to better diagnose the nature of the polar feedback and its ability to influence the global water cycle.

References: [1] Haberle R. M. et al. (2012) LPSC. [2] Kahre M. A. et al. (2018) COSPAR. [3] Madeleine J-B. et al., (2014) GRL, 41, 4873-4879. [4] Haberle R. M. et al. (2019) Icarus, 333, 130-164. [5] Montabone, L. et al. (2015) Icarus, 251, 65-95.