INTERANNUAL VARIABILITY OF WATER ICE OPACITY AT GALE CRATER FROM GROUND-BASED CURIOSITY AND ORBITAL MARS EXPRESS OBSERVATIONS.

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Introduction: The Aphelion Cloud Belt (ACB) is a water ice cloud band that encircles Mars longitudinally at latitudes ranging from about 10°S to 30°N (Fig. 1) during the northern spring and summer (L_s ~ 0°-180°; aphelion season) [1]. The ACB forms when water vapor sublimated from the north polar cap reaches the tropics and is incorporated into the upwelling branch of the solsticial Hadley cell, becoming saturated at relatively low condensation levels compared to those at the perihelion season when atmospheric temperatures are warmer [1,2].

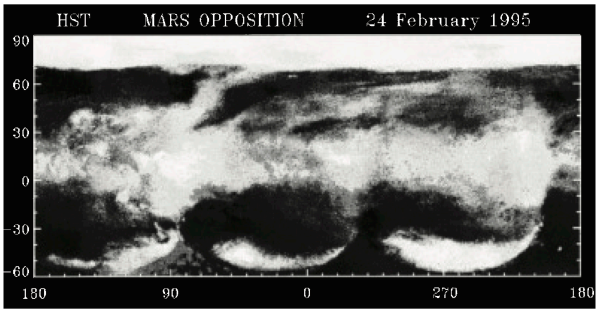

Figure 1. Hubble Space Telescope imaging of Mars at 410 nm at L_s = 68°. The ACB extends globally at low latitudes between 10°S-30°N. The bright region above 70°N corresponds to the retreating seasonal and residual polar cap and the cloud arcs between 30-60°S correspond to the southern polar hood. From [1].

The ACB is an important component of the current Martian climate system, playing a key role in the seasonal evolution of the water vapor cycle by controlling its cross-equatorial transport and in the atmospheric and surface thermal structure through its radiative effects [2,3].

The ACB has been studied extensively using satellite observations over the last two decades [4], showing a striking repeatability with values of water ice opacity and distribution of water ice clouds being nearly identical from year to year. However, this repeatability has recently been challenged by rover-based measurements from various instruments onboard the Mars Science Laboratory (MSL) Curiosity and by orbital measurements by the Planetary Fourier Spectrometer (PFS) onboard Mars Express (MEX) at the location of Gale crater (4.7°S). Here we show observational results from both missions indicating a significant increase in water ice opacity (up to 50%) from Martian Year (MY) 32 to MY 33.

Interannual Variability from Orbital Measurements: Systematic and continuous monitoring of the ACB started in 1997 with the beginning of Mars Global Surveyor (MGS) operations, followed by the Mars Odyssey (MO), MEX and Mars Reconnaissance Orbiter missions. Retrievals of water ice opacity (τ_{ice}) by the Thermal Emission Spectrometer onboard MGS from MY 24, L_s = 104°, to MY 26, L_s = 180° and by the Thermal Emission Imaging System onboard MO from MY 25, L_s = 330°, to MY 29, L_s = 183° suggest that the ACB is remarkably repeatable, with values of τ_{ice} and distribution of water ice clouds being nearly identical from year to year [5,6].

Evidence for Interannual Variability at Gale from MSL Data: The striking repeatability of the ACB as measured from orbit has recently been challenged by rover-based measurements from various instruments onboard MSL Curiosity at Gale. Foremost, retrievals of water ice opacity from passive mode observations of scattered skylight by the MSL/ChemCam instrument show an unexpected increase in τ_{ice} of up to 50% from MY 32 to 33 (Fig. 2). The local time at which these measurements were performed did not vary substantially from year to year, and thus interannual changes in τ_{ice} are not expected to be caused by variations within the diurnal cycle [7].

A similar increase (up to ~30%) in water ice opacity in MY 33 relative to MY 32 has also been observed from afternoon images pointing toward the zenith taken by the MSL Navigation Cameras. In this case, we note that the increase in τ_{ice} might be caused by a bias in the diurnal distribution of images, with more early morning observations acquired in MY 33 compared to MY 32 [8].

Moreover, indirect evidence for an increase in τ_{ice} from MY 32 to 33 is provided by analyses of UV flux data measured by the MSL Rover Environmental Monitoring Station (REMS). Dust effective radii obtained from REMS UV measurements during the aphelion season of MY 33 are lower than those obtained in MY

32 [9]. Such lower values can be partially attributed to a larger contribution of water ice clouds to the total atmospheric opacity during the aphelion season of MY 33, which was not considered in [9], and which likely led to an underestimation of the retrieved dust particle size.

More indirect evidence for an increase in τ_{ice} from MY 32 to 33 has been provided from ground temperature observations by the MSL/REMS instrument in combination with numerical modeling [10]. The seasonal evolutions of the modeled and measured mean and minimum ground temperature diverge from each other during the fall each year, reaching a maximum deviation of ~10 K near the peak of southern winter in MY 33. By adding an extra term to the downwelling IR flux in MY 33, [10] obtained a better fit to measured diurnal mean and minimum ground temperature. Such a term is consistent with a heightened presence of water ice clouds above Gale crater in MY 33.

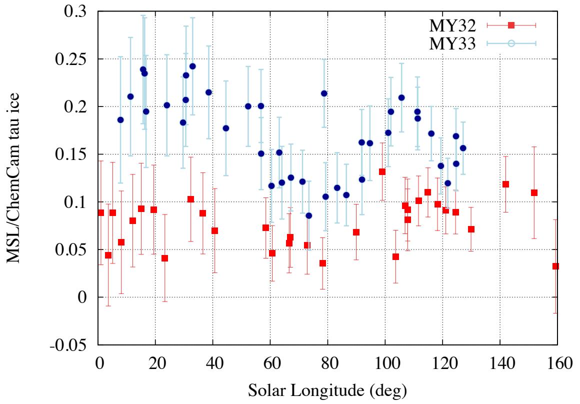

Figure 2. Water ice opacity values as a function of solar longitude retrieved from observations of scattered skylight by the MSL/ChemCam instrument in MY 32 (red) and 33 (blue).

Evidence for Interannual Variability at Gale from PFS Data: Special PFS spot-tracking observations performed over Gale are dedicated to the analysis of the atmospheric parameters above Gale, including water ice opacity. Most of the PFS observations are acquired in nadir pointing and can be used to investigate diurnal, spatial, and seasonal evolution of ice opacity within the ACB [11]. Preliminary results of interannual variability of water ice opacity over Gale crater retrieved from PFS spot-tracking observations are shown in Fig. 3 for MY 32 and MY 33.

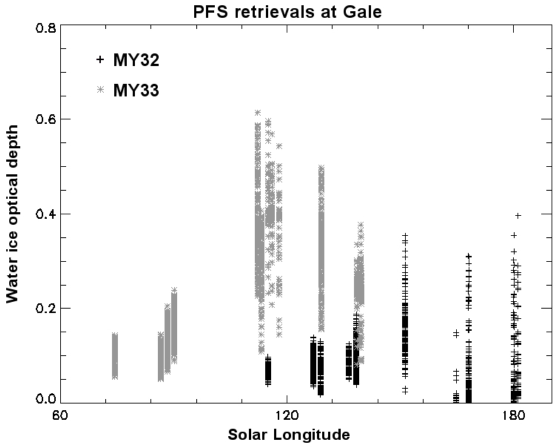

Figure. 3. PFS water ice retrievals (825 cm^{-1}) at the location of Gale, suggesting an increase in τ_{ice} from MY 32 to 33, in accordance with ChemCam retrievals shown in Fig. 2. Note that the time at which the selected retrievals were performed varies between years and time of the season in the range 7-12 h local time.

PFS retrievals suggest a significant increase in τ_{ice} from MY 32 to 33, in accordance with ChemCam retrievals shown in Fig. 2. PFS retrievals were performed at different local times depending on the Martian Year and time of the season and therefore an assessment of the interannual variability at Gale from orbit requires a careful analysis. Estimated uncertainty for τ_{ice} is 0.01 [11].

Future Work: We plan to further analyze orbital MEX/PFS data at the location of Gale in combination with rover-based MSL data to understand the interannual variability of water ice clouds in Gale, its relation with the local water vapor cycle and its impact on the near-surface environmental conditions.

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