THE METEOROLOGY OF DUST AND WATER ON MARS: INSIGHTS FROM THE RECENT PAST AND NEW CHALLENGES N.G. Heavens[1], [1]Department of Atmospheric and Planetary Sciences, Hampton University, 23 E. Tyler St., Hampton, VA, 23668 (nicholas.heavens@hamptonu.edu)

Introduction: In common with the Earth, Mars has coupled cycles of dust and water that have shaped the planet's weather, climate, and polar geological archives over the course of the recent past. The relative dominance of dust and water with respect to the Earth's weather is reversed on Mars, whose most significant weather systems are full of dust, not water.

During the telescopic and Mariner-Viking eras of exploration, nadir and limited limb observations as well as data from the Viking weather stations established the basic climatology of the dust and water cycles: (1) a (dust-) clear season of limited interannual variability in northern spring and summer, whose dominant tropical phenomenon is widespread water ice clouds; and (2) widespread local dust storm activity in southern spring and summer, characterized by a high degree of interannual variability with respect to the growth of dust storms to regional and global size [1]. Selective interpretation of these observations also suggested that the atmospheric dust haze was approximately uniformly mixed, except in association with some types of dust storm activity [2,3]. The vertical distribution of water vapor was modeled to fall off quickly with height above a seasonally-varying hygropause at ~20 km at northern summer solstice and ~40 km at southern summer solstice [4].

Since the last International Conference on Mars, there has taken place intensive analysis of limb observations by instruments on Mars Global Surveyor (MGS): particularly the Thermal Emission Spectrometer (TES), Mars Reconnaisance Orbiter (MRO): particularly Mars Climate Sounder (MCS) and the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM), and Mars Express (MEx): particularly Spectroscopy for Investigation of Characteristics of the Atmosphere of Mars (SPICAM) [5-10]. These observations show: (1) layers of dust and water vapor detached from an approximate uniform distribution near the surface: (2) significant diurnal variability in the dust distribution of the atmosphere; and (3) extreme detached dust layers during regional and global dust storm activity. These observations are reviewed below.

In the presentation itself, I will synthesize what these observations suggest about Mars's meteorological dynamics. In particular: (1) the similarity in specific heating rates due to radiative heating of dust on Mars and latent heating in moist convective clouds on Earth results in a strong analogy between mesoscale moist convective weather systems on Earth and sub-synoptic dusty weather systems on Mars: the dynamics of the tropical cyclones therefore are mostly reproduced in Mars's tropical dust storms; (2) water ice cloud scavenging limits the growth of dusty weather systems.

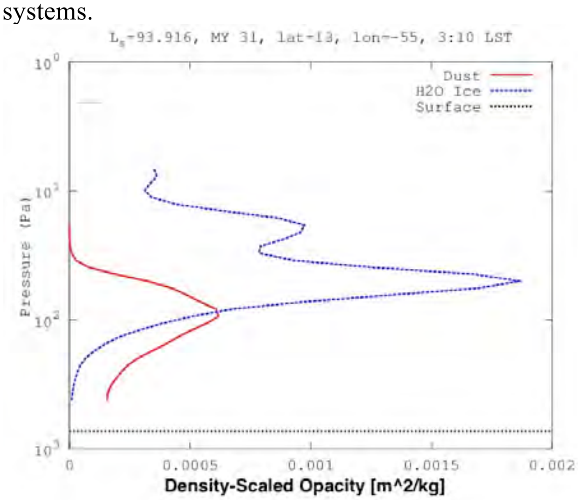

Figure 1: Example of a detached dust layer observed by MRO-MCS. Note how the dust layer is capped by a water ice layer.

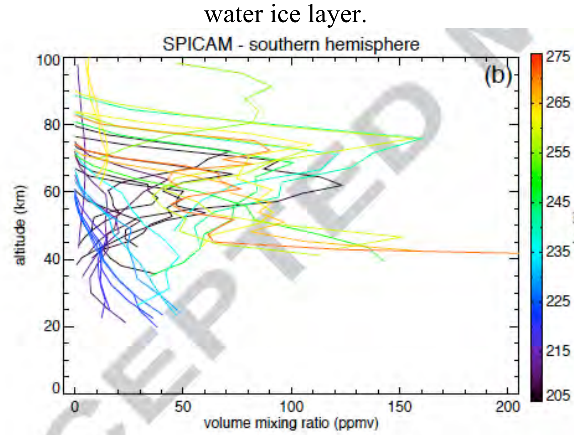

Figure 2: Detached water vapor layers observed by MEx-SPICAM. Line coloring plots season, showing an increase in layer magnitude and altitude in the southern hemisphere during the course of the spring [10].

Detached Layering of Dust and Water: Observations by MRO-MCS showed that the vertical dust distribution was not uniformly mixed to some height and decreasing in dust mass mixing ratio with height at higher altitudes [6,7]. (The Conrath-ν profile is a similar functional form that arises from balancing the competing effects of sedimentation and vertical eddy diffusivity [2].) Instead, dust mass mixing ratio may increase with height to form a layer of enriched dust mass mixing ratio significantly above Mars's planetary boundary layer. Dust then falls off with height thereafter to form a "coniopause" (the dust feature analogous to a hygropause). These enriched layers ("detached dust layers") are common in the tropics throughout the year and near the summer pole. Over much of the year, they form a climatological zonal average structure known as the "high altitude tropical dust maximum" or "Lower Dust Maximum" (LDM) at 15-30 km above the surface of the tropics [6-7].

Retrievals from MGS-TES limb observations, MRO-CRISM limb observations, and solar occultation observations by MEx-SPICAM confirm the existence of detached dust layers [5,8-9]. MGS-TES limb observations found a second region of climatological focus for detached dust layers at 45-65 km above the surface: "the upper dust maximum" (UDM) [5]. MEx-SPICAM possibly observes the UDM but cannot distinguish dust and water ice [9]. I will report a small number of detached dust layers, which are not only enrichments but are substantially above the coniopause. By the time of the meeting, I may be able to address the robustness of the UDM with MRO-MCS retrievals, thanks to recent refinements to the retrieval algorithm.

Water vapor also is found in detached layers. SPICAM has found detached layers of water vapor as high as 90 km above the surface (Fig. 2) [10].

Diurnal Variability in the Dust Distribution: Observations by MRO-MCS and MGS-TES also show significant diurnal variability in the dust distribution at some seasons [5-7]. At northern summer solstice, the HATDM/LDM feature is much dustier during the day than during the night. The easiest way to see this is to difference pairs of nearby MRO-MCS retrievals from the opposite ends of the same diurnal cycle (Fig. 3). Diurnal variability is at its minimum in early southern summer, when tropical water ice cloud activity at low latitudes is minimal. A manuscript on this work is currently being revised for *J. Geophys. Res.*

Extreme Detached Dust Layers in Dust Storms: In southern spring and summer, detached dust layers are frequently observed, even when diurnal variability in the dust distribution is muted. However, the early stages of regional and global dust storm activity is robustly characterized by "streamers": detached dust layers of comparable mass mixing ratio to the opacity of the dust storm if well mixed form detached dust layers that stretch from the southern tropics (where the lifting centers are) into the northern extratropics (Fig. 4). The dust distribution in the later stages of dust storms becomes uniformly mixed, consistent with [2].

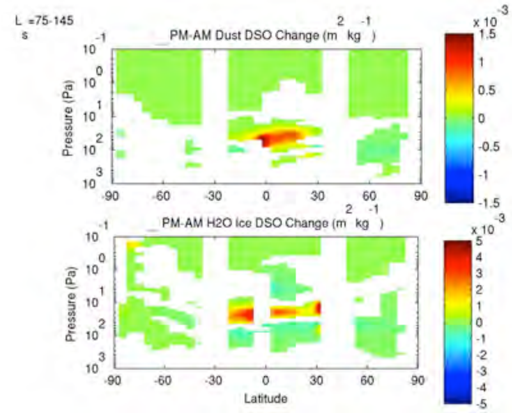

Figure 3: Average night to day change in dust and water ice density-scaled opacity in late northern spring and summer (MRO-MCS). Changes in the water ice layer are centered 0.5-1 scale heights above the changes in dust. Changes are comparable to the dust density-scaled opacity at a given altitude at night.

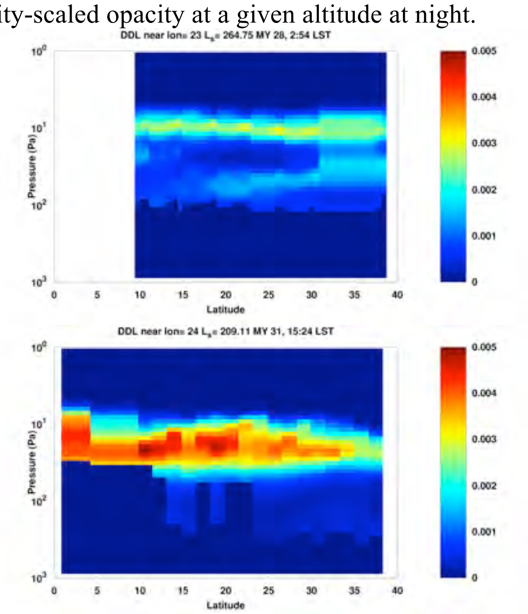

Figure 4: MRO-MCS observations of "streamers" at ~40 km above the surface, associated with the global dust storm of June-August 2007 (top) and a regional dust storm in November of 2012 (bottom). The deepest blue color indicates no data.

References: [1] Zurek R.W. et al. (1992), *Mars*, Tucson, AZ: U. Arizona Press, 835-933. [2] Conrath B.J. (1975), Icarus, 24, 36-46. [3] Leovy, C.B. et al. (1972), Icarus, 17, 373-393. [4] Richardson, M.I. and Wilson, R.J. (2002), Nature, 416, 298-301. [5] Guzewich, S.D. et al. (2013), JGRP, 118, 1-18. [6] Heavens, N.G. et al. (2011), JGRP, 116, E04003. [7] Heavens, N.G. et al. (2011), JGRP, 116, E01007. [8] Smith, M.D. et al. (2013), JGRP, 118, 321-334. [9] Määttänen, A. et al. (2013), Icarus, 223, 892-941. [10] Maltagliati L. et al. (2013), Icarus, 223, 942-962.