CONSTRAINTS ON ATMOSPHERIC WATER VAPOR AND CIRCULATION AT GALE CRATER FROM THE MSL ATMOSPHERIC MONITORING CAMPAIGN

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Introduction: The Mars Science Laboratory (MSL) Rover provides an effective platform from which the atmosphere at Gale Crater may be observed. Temperature of the ground and of the air, atmospheric pressure, ultraviolet irradiation and relative humidity are provided by the Rover Environmental Monitoring Station (REMS). To add value to these measurements and extend our understanding of the broader atmosphere away from the Rover, a campaign of atmospheric imaging has been undertaken using the Navigation Cameras. Individual atmospheric movies for monitoring the motions of dust and ice in the atmosphere are described by [1] and these have been augmented by a concerted search for dust devils and early morning imaging for frost using the Mastcam. From these datasets we are able to place constraints on the circulation of the atmosphere within Gale Crater as well as the quantity of atmospheric water vapor and dust. Each investigation thrust and its findings to date will be discussed in turn before synthesizing all together.

Background: Previous work by [2] had demonstrated that low-lying topographically confined fogs were visible at many equatorial locations in the early morning. While not predicted by atmospheric models [3] such condensation would explain the diurnal variability observed in neutron data at low latitudes [4]. However, such condensation was not directly observed at Gale and there is now reason to suspect that the circulation within this structure may be unusual compared to other equatorial craters. Models [5] suggest that because of the central mound at Gale, the mixed boundary layer may be suppressed, perhaps no thicker than 1 km. Furthermore, studies [6] using blue-to-red ratios have found that the variability in optical depth and the timing of the occurrence of clouds and hazes is unusual compared to other candidate MSL landing sites.

Variable Layer Optical Depth: [7] used a technique to extract the optical depth of clouds and dust density variations using the time-varying image contrast in atmospheric monitoring movies and the background optical depth. A similar analysis here using [8] shows that variable optical depths are rarely more than ~0.01. Based on data from the Phoenix Mission [7] and observed morphology, such values are more consistant with dust than with condensation. Only a single observation of clouds has been made [1] and these were very thin and are interpreted to be remnants of the aphelion cloud belt.

The Scale of Dust Billowing: The wide viewing angle of the Navigation Cameras (45 x 45 degrees) allows the size of individual dust billows to be discerned. At Gale Crater such billows are angularly smaller than at Phoenix by a factor of between two and four. Since the atmospheric eddies that drive variations in density should be of similar size at Green Valley and Gale, the small angular size of the billows suggests that these features are located higher in the atmosphere.

For Phoenix, dust was concentrated in the first 4 km of the atmosphere [9]. If the features at Gale are of similar size this would suggest a characteristic height of greater than 5 km, above the level of the crater rim.

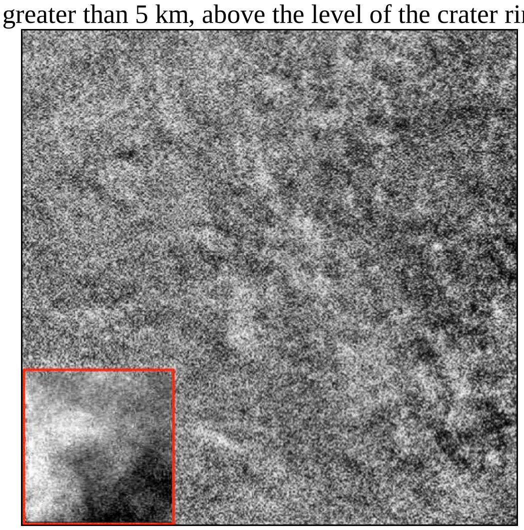

Figure 1: Dust Billows observed on sol 49 of the MSL Mission compared to similar features from Phoenix [7] on sol 12 (inset) shown at the same angular scale. The smaller size of billows at Gale Crater suggests higher altitudes for these features.

Direction of Dust & Clouds: It is expected from modeling [5] that wind direction will change with height at Gale. Furthermore, such an interpretation is consistent with the HiRISE-observed surface distribution of the SkyCrane stage, parachute, heat shield and spacecraft locations at the time of landing. Unfortunately, measurement of winds has proven difficult. Locally this has been hampered by damage to one of the REMS booms by rocks kicked up at landing [10]. Aloft, zenith movie wind determination has been hampered by low contrast and the high solar altitude during most of the period when MSL is operating.

However, those zenith movies which show coherrent structures [1] are suggestive of very high clouds above the crater rim, consistant with orbital tracking using MARCI instead of the lower-level circulation. In the late afternoon (~1600 LMST), zenith wind directions cluster near 300° whereas REMS reports values between 230°-270° (meteorological, i.e. with wind originating clockwise from N).

Line-of-Sight Extinction: Previously, [11] has shown that variations in the line-of-sight extinction can be used to determine the stratification of dust in the atmosphere on Mars. Analysis of the visibility of the rim walls at Gale consistently returns values in the neighborhood of 0.03 km^{-1}, about half of the extinction value derived from column-averaged optical depth [8]. This would suggest that either there is relatively little mixing of higher altitude air derived regionally with the air nearest the surface within the crater.

Dust Devil Searches: As of sol 90, despite significant observations, there is only one likely detection of a dust devil. For instance, during the period of 1100 LMST to 1200 LMST, when REMS pressure drops are most abundant [12] a total of 1.14 km^2 has been surveyed using atmospheric monitoring movies. Such a search would be expected to observe as many as 185 devils if they are 6 m in diameter [12]. This suggests that devils in Gale are dustless, which could also explain the non-detection of dust devil tracks from orbit.

Mastcam Frost Spot: On sol 44, a spot near the rover was imaged in the 440-nm and clear filter to produce blue to red ratios. Such color ratios have previously been used [13,14] to determine the thickness of frosts. Furthermore, modeling [5] suggested that this would be a likely time to find frosts. However, a detailed analysis of the ratios shows no conclusive evidence of frost formation on this sol. Given that measured REMS ground temperatures are nearly 20 K below the model-inferred frost point, the partial pressure of water vapor in the mixed boundary layer could be as low as 4% of the expected value [15]. However, it is more likely that physisorption and chemisorption sequester water vapor near the surface, locally lowering the vapor pressure below that required for frost.

Synthesis and Conclusions: When combined together, the variable layer optical depth, the scale and direction of the features, the line of sight extinction and the Mastcam frost spot all suggest that conditions at Gale may be particularly dry near the surface during the period covered by the first 90 sols of the mission (L_s = 151° to Ls = 203°). If this proves to be the case year-round in the current era, Gale may have an enhanced ability to preserve any biosignatures that might be degraded by interactions with atmospheric water.

Furthermore, the relative lack of contrast in visible features, either dust billows or dust devils, may indicate low levels of dust in the lower part of the atmosphere compared to the entire column which suggests a low level of mixing of the planetary boundary layer with the upper atmosphere at Gale. However, the dust storm which was incipient during the end of the initial 90 sols shows significant quantities of dust entering into the crater below the 5 km level, as evidenced by a visible increase in opacity towards the rim wall.

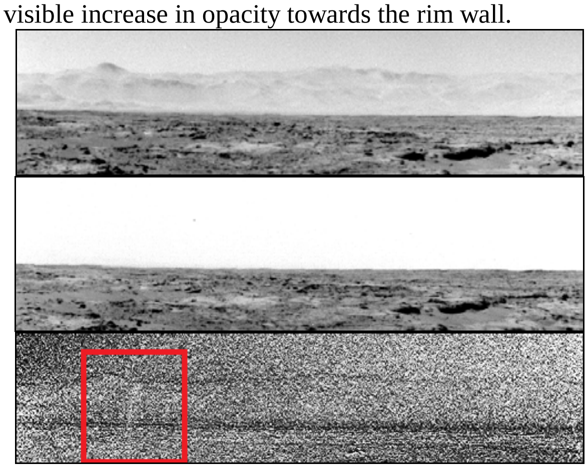

Figure 2: The north rim of Gale Crater as imaged with identical processing before (above) and after (middle) the onset of the dust storm incidcating a large increase in the amount of dust below the 5-km level within the crater.The same scene on sol 41(bottom) shows a subtle bright column (red box), identified as a possible dust devil. This feature remains coherent and translates right to left over several frames.

Acknowledgements: This work is supported by the NASA MSL PSP, with funding from the CSA. We are particularly indebted to M. Malin and the MastCam system for the frost spot radiometry.

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