OBSERVATIONS OF CLOUDS AND WINDS ALOFT AT GALE CRATER. R. Francis[1], J. Moores[1,2], J. Maki[3], D. Choi[4], E. McCullough[1], The MSL Engineering Camera Team, and The MSL Science Team, [1]Centre for Planetary Science and Exploration (CPSX), Western University, London, Ontario, Canada, raymond.francis@cpsx.uwo.ca, [2]Now at Centre for Research in Earth and Space Sciences, York University, [3]Jet Propulsion Laboratory/California Institute of Technology, [4]ORAU/NASA Goddard Space Flight Center.

Introduction: The Mars Science Laboratory (MSL) atmospheric science team has been conducting a campaign of regular imaging of the atmosphere to study clouds, winds aloft, and atmospheric dynamics, with an aim to employing automated analysis techniques to extract wind information from sequences of images. The goal is to characterize the atmospheric dynamics at the Gale Crater landing site of the Curiosity rover.

Motivation: While recent missions have improved our understanding of the martian atmosphere, much remains to be learned about the weather and climate of this planet which can only be revealed by further observations. Of particular interest is the role of water, which can form clouds, be transported by air masses, and interact with surface materials. Efforts to understand the preservation of ancient materials – perhaps including biomarkers – on or near the surface can be informed by understanding their interaction with water and windblown dust. These interactions are in part driven by the transportation of water and dust by the atmosphere, making an understanding of atmospheric dynamics relevant both for investigations of meteorology and of geology.

The goal of these investigations is to provide new data on the behaviour of the atmosphere, including winds aloft and how they correlate to winds near the surface and the transportation of materials, and the interaction of the atmosphere with materials and topographic features on the planet's surface.

Imaging campaign and goals: The imaging campaign uses the rover's NavCam imager to capture sequences of images which can be used to inspect the observed scenes for clouds and dust, and the motions thereof. As conditions allow, the observations are taken at routine intervals of a few sols, to characterize the variety and day-to-day variation of the processes observed. The campaign is planned to continue for the duration of the rover's prime mission, to give a frequent sampling over the course of a full martian year.

Typical observations comprise a sequence of 8 images captured with a spacing of 13 seconds between frames. The observation plan is derived from the successful observations of clouds and wind obtained using the Surface Stereo Imager of the Phoenix Mars lander [1]. The NavCam imager allows the acquisition of images having a wide field of view, while generating a reasonable amount of data per observation.

Three types of observations are made on alternate sols, on a repeating cycle. The *Zenith* observation orients the imager to place the centre of the frame near the local zenith, allowing a view of clouds at any altitude, their morphology and evolution over the duration of the sequence, and, of particular interest, the direction of their horizontal motion. This wind motion provides a measurement of winds aloft, which on Mars is difficult to measure by other means. Such wind-aloft measurements can be compared to surface measurements taken by the rover's wind sensor, part of the Rover Environmental Monitoring Station (REMS) instrument.

The *Mount Sharp* observation places the camera's field of view above the peak of Gale Crater's central mound, and is named after the informal label for this topographic feature in use by the mission team. The aim of this observation is to detect and characterize any cloud associated with the summit, which may suggest orographic influence on local cloud formation.

The *Dust Devil* observation aims the imager near the horizon, aiming to detect visible vortices in the atmosphere of the kind seen elsewhere on the planet [2]. Indications from the REMS instrument suggest such vortices are present [3], though until they are imaged, it will not be clear to what extent they lift and transport dust.

As a baseline, the observations are made on a regular basis on alternating sols. The Zenith observations is scheduled every second sol; the Mount Sharp and Dust Devil observations are scheduled every fourth sol, alternating between the Zenith sols. In practice, mission activities can alter this cadence, and the imaging schedule is adjusted to fit operational requirements.

Initial results: As of MSL sol 90, a small number of sequences show structure suggestive of clouds. One in particular from Sol 24 shows streamers of thin, textured clouds moving across the scene. A portion of a frame from this sequence is shown in Figure 1. It shows narrow bands of cloud arranged diagonally across the frame, most readily seen in the dark band which crosses just below the centre of the frame. When the full set of frames from this sequence is animated, the cloud structures can be followed as they move and evolve, and their motion gives a clear wind vector, which is estimated to be between 290 and 300 degrees from north.

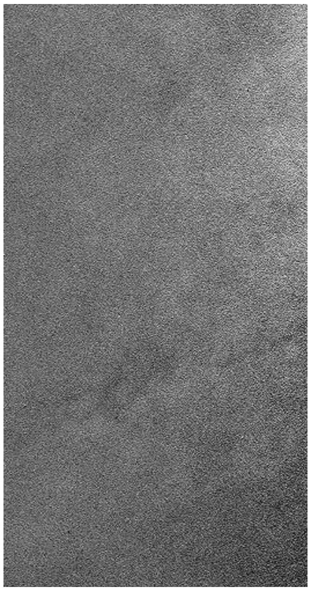

Figure 1- MSL NavCam image showing textured clouds on sol 24

Due to the low optical thickness of these clouds and the strong scattering in the martian atmosphere, contrast-stretching techniques are employed to reveal the cloud textures. Subtraction from each frame in the sequence of the arithmetic mean frame is used, followed by adaptive histogram stretching, similarly to the techniques employed in [1]. As images have been acquired over the course of surface operations, the appropriate dynamic range for the camera has come to be better understood, and adjustments to the imaging parameters have been made to best image these low-contrast features.

Automated processing: In order to improve the accuracy, speed, and efficiency of processing these image sequences, it is planned to use automated image processing techniques. In particular, the determination of the wind-aloft vector displayed by the clouds in the Zenith observations is intended to be made using a computer vision algorithm adapted from the work described in [4]. This algorithm, developed using imagery of terrestrial clouds, has shown success in calculating the wind aloft vector for images from the Phoenix mission originally analyzed in [1], where sufficient contrast existed and perspective distortion was minimized. The characteristics of this algorithm have guided the development and use of the Zenith observation in particular, and of the selection of imaging parameters to obtain the best observations using NavCam.

The technique, described in detail in [4], processes the digital images to enhance the contrast, and uses a normalized cross-correlation technique to match a portion of one frame to its corresponding section in another. The pixel-space displacement between matching areas across images, divided by the length of the interval between images, gives a vector corresponding to the wind direction, and its magnitude in the image space. External information about cloud altitude can be used to relate this pixel-space speed to the linear speed of the clouds in the atmosphere.

A difficulty to this point has been the limited number of frames available which show clear cloud features, as well as their low contrast when compared to the image noise present in the scene. In large part this can be attributed to the current season on Mars, during which, due to warmer temperatures, relatively little condensate cloud is expected to form. Further, there are indications that the atmosphere at the landing site contains less moisture than expected, even at this latitude [5]. The Phoenix mission, operating from a cooler, higher latitude site, found condensate clouds on a regular basis [1], and it is possible that similar phenomena may be observed during cooler portions of the year, even from the low-latitude landing site of MSL.

Extension to dust tracking: A next step for this investigation will be to extend the algorithm for wind determination to cover cases where clouds of high optical opacity are not present. The goal will be to develop a system to extract wind information from the motion of dust in the martian atmosphere, which is ubiquitous even in the absence of clouds. Such a system will require more advanced and adaptive computer vision techniques, and may require higher-resolution imaging.

The successful development of such an extended algorithm would provide a tool which could extract wind-aloft information under most daylight sky conditions, and provide a more complete understanding of the winds by filling in gaps in the data set currently resulting from days with an absence of sufficiently opaque clouds.

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