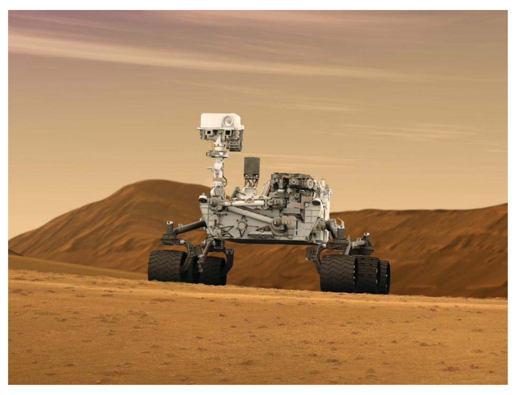
Observations of Clouds and Winds Aloft at Gale Crater

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.

Imaging campaign



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. 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 transport of water and dust by the atmosphere, making an understanding of atmospheric dynamics relevant both for investigations of meteorology and of geology.

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

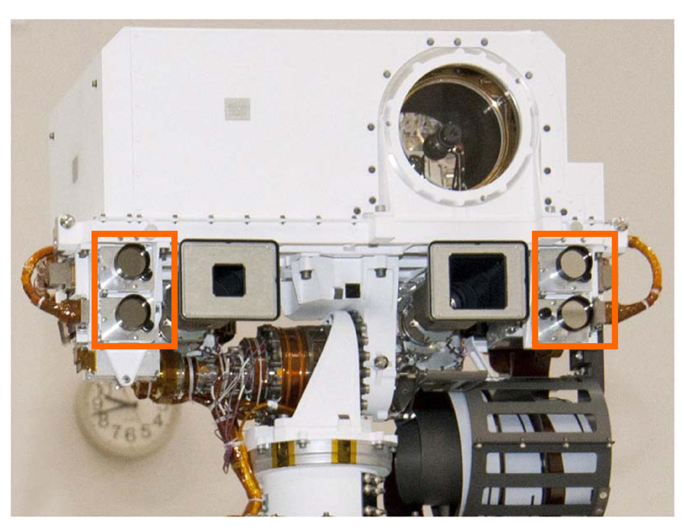
Observation types

Typical observations consist of a series of 8 images captured with a spacing of 13 seconds between frames. The NavCam imager allows a wide field of view, while keeping the data volume low. Three types of observations are carried out routinely, as conditions allow:

Zenith: Upward-pointing images allow direct interpretation of winds-aloft directions

Mount Sharp: The image frame is placed above the summit of Gale Crater's central mound, to watch for summit-associated cloud

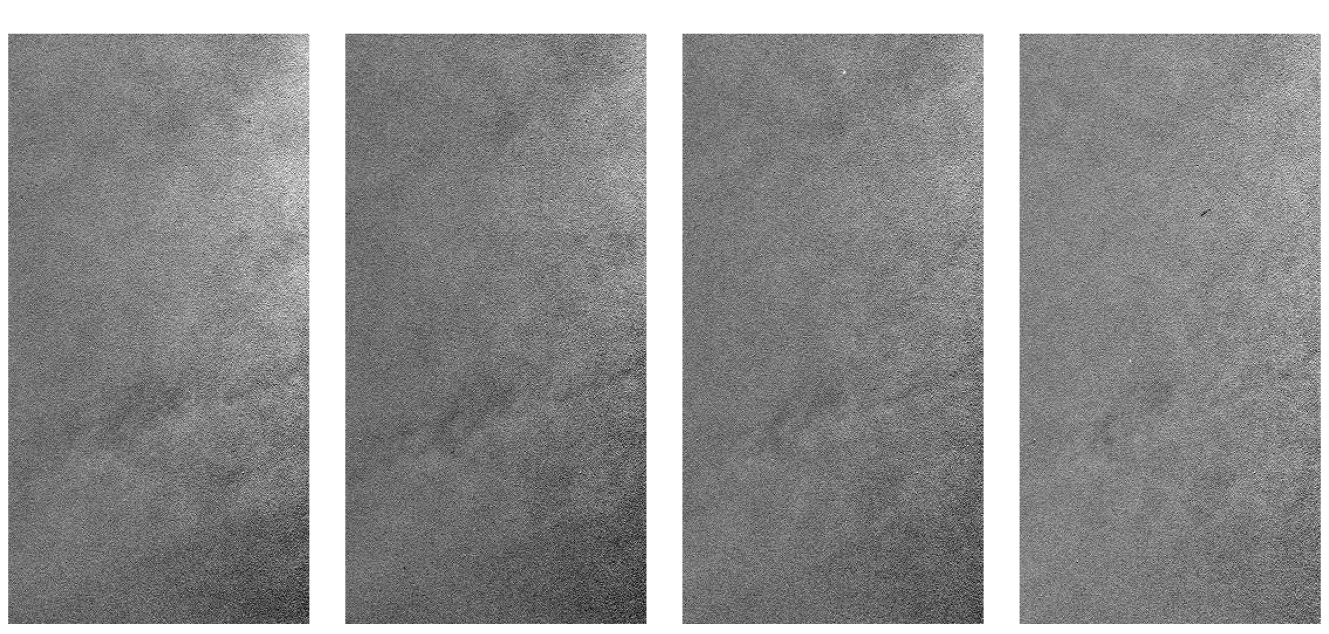
Dust-Devil: The camera is aimed near the horizon to watch for visible vortices of the kind seen elsewhere on the planet [2].



Above: Orange boxes indicate the NavCam imagers on the rover's remote sensing mast

Early observations with MSL

As of MSL Sol 90, a small number of sequences show structures suggestive of clouds. One in particular from Sol 24 shows streamers of thin, textured clouds moving across the scene. A series of subframes from this sequence is shown below. 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 this sequence is animated, the cloud structures can be followed as they move and evolve, and their motion gives a clear wind vector, estimated between 290 and 300 degrees from north (clockwise in azimuth – here counter-clockwise from top, as the scene is viewed from below).

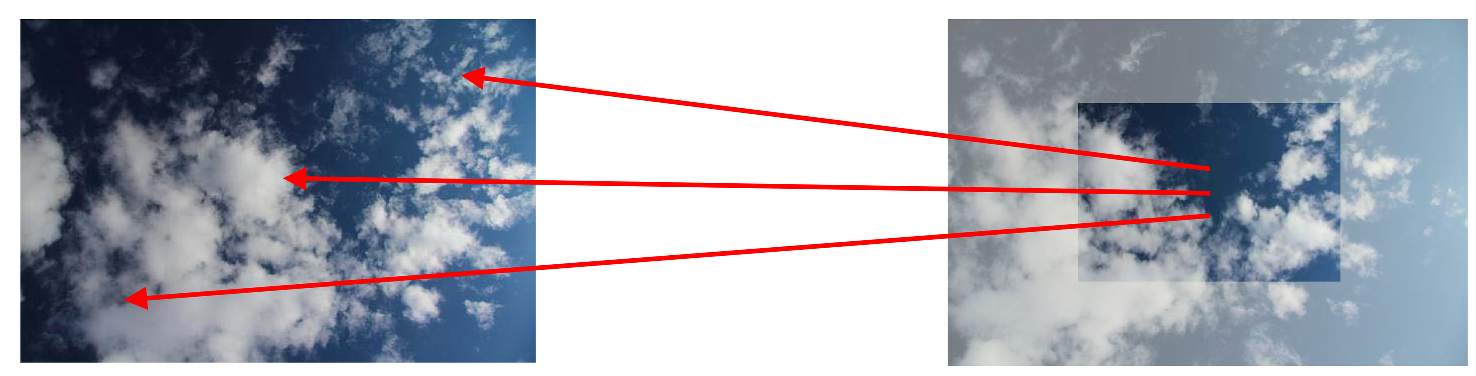


Left: A sequence of NavCam subframes from Sol 24, where thin clouds are seen , underlain by dusty air, as they move and change over several frames at 13-second intervals

Computer vision

In order to improve the accuracy, speed, and efficiency of processing these image sequences, automated image processing techniques have been developed. The method, 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. The use of such an area-based method reduces errors due to changes in the clouds themselves between frames.

Because the clouds observed on Mars often have low optical thickness, while the dust present in the atmosphere is highly scattering, contrast-stretching techniques are employed to reveal the cloud textures. The arithmetic mean of all frames in a sequence is computed, and subtracted from each frame, which is then processed by adaptive histogram stretching, after the techniques in [1].



Above: In the cross-correlation technique, the centre portion of one image is compared to all regions of an earlier image in the sequence to find the area of greatest similarity. The vector between that location and the centre represents the wind direction, here almost directly leftward in images from the Canadian Arctic. The technique has shown success with images from both Earth and Mars, with a variety of cloud morphologies.

Right: Cloud features are visible in two frames acquired 69 s apart by one camera of the Surface Stereo Imager on the 2008 *Phoenix* spacecraft.

Far Right: The centre portion of the second (right-hand) frame is overlain in red on the earlier frame at the position of best correlation. The vector which returns it to the centre represents the wind direction.

Next steps

Given the infrequent occurrence of clouds compared to that observed at the Phoenix site [1], 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 periods with an absence of sufficiently opaque clouds.

References: [1] Moores J. E. *et al* (2010) *JGR,* 115, E00E08. [2] Greely R. *et al* (1997) *JGR,* 111, E12S09. [3] Kahanpää *et al*. (2013) *LPS XXXXIV* (this meeting) [4] Francis R. *et al.* (2012), Proceedings of 63rd IAC, IAC-12,A3,3B,10,x14399. [5] Moores *et al*. (2013) *LPS XXXXIV* (this meeting).

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