DUST DEVILS IN GUSEV CRATER: A SECOND YEAR OF OBSERVATIONS BY THE SPIRIT ROVER. Geoffrey A. Landis[1], P.G. Geissler[3], R. Greeley[2], M.T. Lemmon[4], J. Maki[5], L.D.V. Neakrase[2], S.D. Thompson[6], D. Waller[2], P.L. Whelley[2], and the MER Athena Science Team, [1]NASA John Glenn Research Center, 21000 Brookpark Road, mailstop 302-1, Cleveland OH 44135, geoffrey.a.landis@nasa.gov, [2]School of Earth & Space Exploration, Arizona State University, Tempe AZ 85287, [3]U.S. Geological Survey, Flagstaff AZ 86001 [4]Department of Atmospheric Sciences, Texas A&M University, College Station TX 77843, [5]Jet Propulsion Laboratory, Pasadena CA 91109 [6]Department of Geological Sciences, University of Nevada at Reno, Reno NV 89557

Introduction: Dust devils are a visible aspect of thermally-driven convection in the surface layers of the atmosphere of Mars. A dust devil features a rotating mass of rising, heated air (a "thermal") that lifts sufficient dust from the surface to be marked by a visible dust column. They have been observed both from orbit [1] and from the surface [2-4]. Passage of such thermals over the meteorology station of the Mars Pathfinder lander were associated with a 1-5 Pa drop in atmospheric pressure [4]. Orbital images show that passage of dust devils leave behind visible tracks where light-colored dust is removed to reveal darker surface beneath; such tracks were abundant near the Spirit landing site, but not visible at the Opportunity landing site, which has a lower albedo and correspondingly less surface dust.

Dust Devils Viewed by MER: The Spirit rover observed dust devils from the Gusev Crater landing site (latitude 14.6°S, longitude 175.5°E) during its first spring and summer on Mars, over a period corresponding to heliocentric longitude Ls of 173° to 340° (*i.e.,* the start of spring through mid-summer in the southern hemisphere) [4]. At the Meridiani site (1.9°S, 354.5°E), no dust devils were observed by Opportunity during the mission. This indicates either that conditions for thermals were not present, or that the thermals failed to lift dust, possibly due to a lower amount of surface dust, or larger or less mobile grains.

After the first dust devils were seen, we undertook a regular campaign to observe them when time was available, using successive Navcam frames to capture the motion. Navcam was chosen because its 45° field of view (compared to the Pancam 16° field of view) allowed a large area to be surveyed. Some dust devils were also seen in both Pancam and hazcam images.

Dust devils observed by Spirit are lighter in color than the background plains, and very slightly darker than the ambient sky. The dust devils varied in morphology from narrow, well-defined vertical columns to broader and more amorphous masses of dust, and may or may not include a "skirt" of material around the base. Figure 1 shows two dust devils in synthesized color, observed by Pancam on sol 574. As can be seen, the red/blue color characteristic of the raised dust is similar to that of the sky, showing that it is reasonable to expect the optical properties of dust in dust devils to be similar to that of dust in the sky. The broad, unstructured shape most likely indicates that this dust devil is in the process of dissipating.

Second year of Dust Devil survey in Gusev: Near the beginning of Spirit's second spring on Mars, the rover observed signs of dust motion on sol 1076, with the first clearly-defined dust devil on sol 1086 (16 sols before the Martian equinox). The Spirit rover is in a different location from the first season's observations, in the "Inner Basin" region south of the Columbia Hills (compared to observations from the upper slopes of Husband Hill for the first season). The lower elevation and obscuration by the Columbia Hills means that a smaller area of plains is visible for the survey.

As of sol 1158, we have observed 19 dust devils in the second season of observations from Spirit, including several imaged serendipitously during observations taken for other purposes, and visible only in a single frame. In addition, we have seen several instances of blowing dust (which may be the remains of dust devils that dissipated before the imaging sequence started.)

Figure 1: Dust devils viewed in color on sol 574. The Pancam filters in this image are L6 (480 nm) for the blue, and R2 (750 nm) for the red, while green was synthesized as a linear mix of the red and blue to make a color image.

The distance from the rover is determined by locating the dust devil based on surface features from orbital images (*e.g.,* HIRISE). The average diameter for the 16 dust devils that could be measured is 23.7 m, and the approximate horizontal velocity is 4.5 m/s.

Figure 2 shows a Navcam image of a recent well-formed dust devil over the course of about three minutes on sol 1120, showing the dust devil as it loses coherence and dissipates. Note that the image is motion enhanced (that is, the contrast has been stretched on the pixels that change between frames); this enhancement makes the dust devil more noticeable. It is about 2.7 km northeast of the rover, and has a height of about 405 m and a diameter of about 12 m (±10%). The dust devil is drifting to the north at about 2.9 m/s, and measurement of vertical motion in the column shows an upward motion of about 3.5 m/s.

An algorithm for automated dust devil detection, WATCH, was developed [5] which searches for changes between identically pointed frames. This has been uploaded to the rover, and the WATCH command detected its first dust devil autonomously on sol 1147, when two dust devils were found in a Navcam movie.

Data Analysis: The optical depth of dust raised by a dust devil can be determined from the radiatively-calibrated brightness during the passage of a dust devil in front of the background feature. The contribution to the brightness of a given pixel from the background feature is (from Beer's law):

$$I_g = I_{g0} e^{-\tau_d} \quad (1)$$

while the contribution to the brightness contributed from the dust devil itself is

$$I_d = I_\infty (1 - e^{-\tau_d}) \quad (2)$$

where τ_d is the optical depth of the dust devil along the line of sight, and I_∞ is the brightness of a dust column of infinite optical depth. The total brightness of the pixel is the sum of these two components, $I=I_g+I_d$. By comparing the same pixel of an image the passage of the dust devil (*i.e.,* at τ_d=0), the optical depth along the line of sight is extracted [4]. Optical depth can also be calculated from measuring the brightness of the dust devil's shadow. By incorporating data on the size of the dust particles (from optical scattering data of sky brightness [6]), these measurements allow calculation of the rate and amount of material lofted.

References: [1] P.C. Thomas and P.J. Gierasch (1985) *Science 230,* 175-177. [2] S.M. Metzger, J.R. Johnson, J.R. Carr, T.J. Parker, and M. Lemmon (1999), *Geophys. Res. Lett. 26*, 2781-2784. [3] J.T. Schofield *et al*. (1997) *Science 278,* 1752-1758. [4] R. Greeley *et al.* (2006) *JGR 111*, No. E12S09. [5] A. Castano *et al.* (2006) *LPS* XXXVII, abstract #2059. [6] M. Lemmon *et al.* (2004) *Science, 306,* 1753-1756.

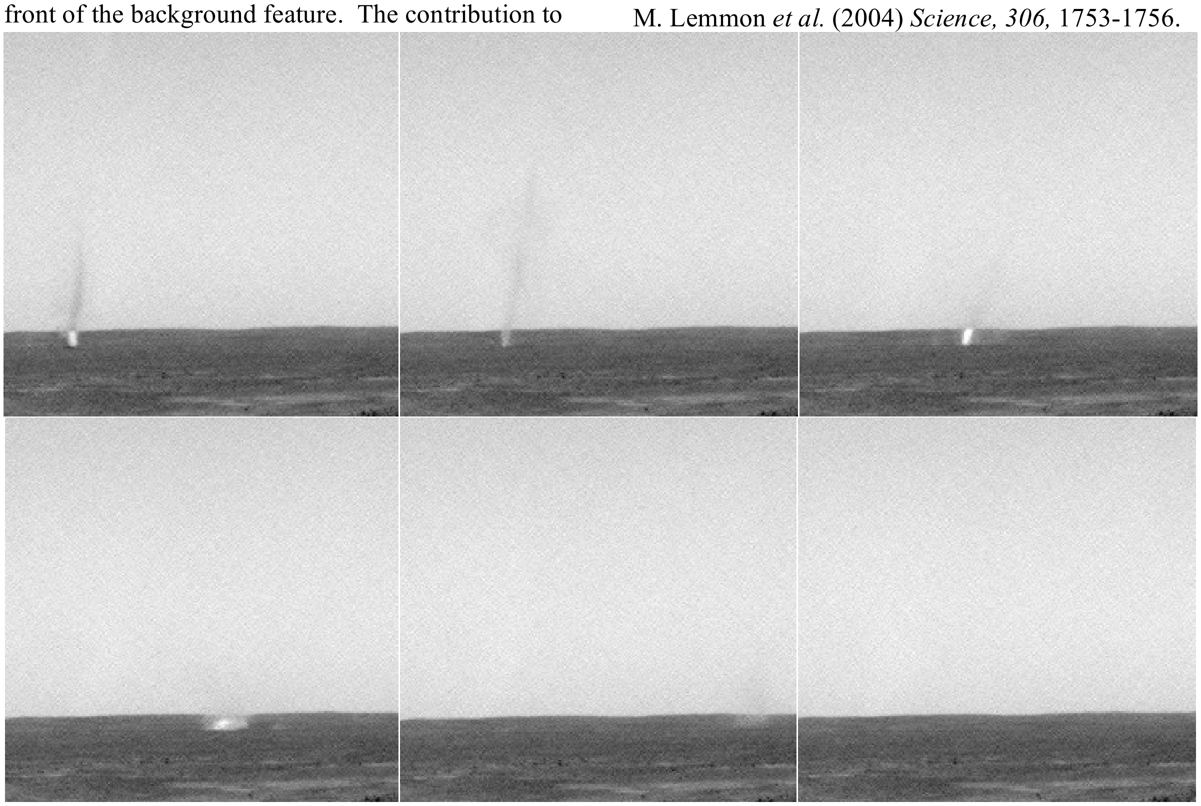

Figure 2: Six frames of a movie taken by the MER-A Navcam on sol 1120, showing a dust-devil moving downwind (North) and then dissipating. The sequence begins at 12:42 local true solar time. The frames are 0, 30, 91, 131, 172, and 230 seconds after the first frame. The contrast on this image has been motion-enhanced.