MARS GLOBAL SURVEYOR MARS ORBITER CAMERA IN THE EXTENDED MISSION: THE MOC TOOLKIT. M. Malin, K. Edgett, B. Cantor, M. Caplinger, S. Davis, E. Jensen, L. Lipkaman, B. Nixon, L. Posiolova, J. Sandoval, K. Supulver, R. Williams, R. Zimdar, Malin Space Science Systems, Inc., P.O. Box 910148, San Diego, CA 92191-0148 USA.

Introduction: The Mars Global Surveyor (MGS) extended mission began 1 February 2001. A second extension authorized operations through 1 October 2004. A 3rd extension, through December 2006, is being considered. The Mars Orbiter Camera (MOC) has acquired more than 165,000 narrow angle (NA) and wide angle (WA) images over a period spanning > 3 Mars years. This paper documents the basic MOC "toolkit"—the types of images and data acquisition techniques used in the extended mission. The MOC investigation was described by Malin et al. [1]. Malin and Edgett [2] gave a summary of operations through the primary mission.

Mission Subphases: MOC images from the 1st Mars year of the extended mission are indicated by the prefix, E*xx*; E denotes "Extended" mission; *xx* is the month from E01 (February 2001) through E23 (December 2002). Data from the 2nd Mars year of the extended mission are indicated by R*xx* (R for "Relay" because it is the period that includes use of the MGS/MOC/Mars Relay system to send data from the Mars Exploration Rovers to Earth), starting with R01 (January 2003).

MOC Experiment: The MOC is a versatile instrument, and the investigation conduct is highly adaptable to changing conditions on Mars, changes in data rate, and changes in mission objectives. MOC consists of 3 separate cameras (1 panchromatic NA, 1 red WA, 1 blue WA). The NA camera provides views at 1.4–12 m/pixel; since 2003 it has also been used for select, sub-meter imaging (~50–70 cm/pixel). The two WA cameras obtain pictures from 240 m/pixel to 7.5 km/pixel and are used to monitor weather and seasonal frost, provide context for NA views, and locally monitor features of interest.

Narrow Angle Camera Toolkit: *Full-Resolution Imaging.* A full-resolution MOC image from nominal mapping altitude is typically 1.4–1.6 m/pixel. Full-resolution images usually cover very small areas on the martian surface. From the nominal orbit, the maximum width of a MOC image is about 3 km; full-resolution images are limited in downtrack extent (usually, 3 to 10 km) by the size of the MOC buffer. During the primary mission, a 3–10 km downtrack size was usually insufficient to hit a small, specific target (most such attempts would miss). Full-resolution images have been more frequently acquired during the extended mission owing to improvements in the reduction of spacecraft angular momentum dumps and knowledge of martian topography, gravity, and control network. Typically, since mid-2002, it has been possible to hit a desired MOC target to within a few hundred meters.

Summed Imaging. Most MOC NA images are summed (*e.g.*, a 1.5 m/pixel image, summed 2x, is returned to Earth at 3.0 m/pixel). NA images can be summed 2–8 times. Summing is used routinely to (a) cover more territory than can be viewed in a full-resolution image, (b) improve signal-to-noise, especially in places of known or suspected atmospheric haze (*e.g.*, summing for 2 months following the 2001 global dust storm events allowed an earlier return to NA imaging), and (c) to acquire more photons because of increased dwell time per line for images obtained in twilight or near the terminator.

Repeat Imaging. In the extended mission, MOC is used routinely to image areas that were previously viewed by the camera. The goals of these images are: (1) to study and monitor change, and (2) to obtain relay-16 stereo views of the planet. During the MGS mission, repeat imaging has shown changes over a variety of timescales from weeks (wind streaks, slope streaks, dust devil tracks) to months (south polar CO_2 scarp retreat and seasonal frost patterns). MOC also continues to be used to look for movement of eolian dunes and changes in middle and polar latitude gullies. Relay-16 (R-16) stereo images are designed for 3-D viewing of martian landforms. On 16 August 2001 at 00:40 UTC, the MGS spacecraft was re-oriented along its gravity gradient. The instruments therefore no longer point nadir (except under unusual circumstances, such as recovery from contingency mode); instead, they are oriented 16° backwards relative to the velocity vector of the spacecraft. This orientation results in a fuel savings that may extend the spacecraft lifetime through the end of this decade. A R-16 stereo pair is created by acquiring a new image at the same time of year (similar illumination and seasonal conditions) that a previous, nadir-oriented image was obtained. The advantage of the R-16 configuration is that it does not require rolling the spacecraft to obtain stereo. However, the downside is that ground tracks do not always repeat at the same time of year as a previous one. Nevertheless, useful stereo data have been obtained for hundreds of sites using this method.

ROTOs. Roll-Only, Targeted Observations (ROTOs) are acquired by rolling MGS up to 30° east or west of nadir. This technique has been used routinely since the start of the extended mission to (a) view new

locations—in some cases inaccessible to MOC during the primary mission—of high science interest, (b) look for and monitor changes, (c) provide stereo (3-D) views, and (d) create mosaics of areas including the Mars Exploration Rover (MER) landing ellipses.

PROTOs. Pitch and Roll Targeted Observations (PROTOS) are designed to obtain sub-meter resolution images of Mars. This is a new technique, developed in 2003, in which the spacecraft is pitched at a rate that allows MOC to sample, in the downtrack direction, the surface of Mars at a spatial scale of ~50 cm/line. The cross-track resolution remains ~1.5 m/pixel, and the MOC resolution is limited by diffraction at ~70 cm/pixel. The resulting PROTO images, especially when rolled in a way that compensates for planetary rotation (cPROTO), allow unprecedented sub-meter scale imaging. They typically have better signal to noise (because of longer dwell times) relative to MOC sum 1 (1.4 m/pixel) images, but they only cover small areas, typically about 3 by 3 km in size.

Constant Roll/Fixed Offset. Constant roll, or fixed offset, is a technique developed to increase science return during extended periods when the MGS ground track walk is near 0 instead of the desired ~60 km per 88 orbits. This situation occurred in 2003 and, to save fuel, was not remedied until the first orbit synchronization maneuver (in October 2003) to match timing with the landing of MER-A in January 2004. During parts of May and all of June–August 2003, MGS was held at a constant, off-nadir roll angle which was changed each week to allow imaging of new territory instead of repeating the same areas over and over again. This approach also allowed the opportunity to make several mosaics of interesting targets.

Public Targeting. In August 2003, a web site (**http://www.msss.com/plan/intro**) was launched to make it easier for the science community and general public to input suggestions for MOC NA targets. This enhances science return by ensuring that the MOC operations staff will not miss an opportunity to image something considered to be important. Over 700 requests were received in August 2003–January 2004.

Special Targeting. It is possible, on occasion, to acquire special image targets other than that of the martian surface. These are rare opportunities, although MOC routinely images stars, about every 12 months, to re-calibrate and focus the camera. Special targets acquired by MOC in 2003 required rolling the spacecraft to point at Earth, Moon, and Jupiter (May 2003) and Phobos (June 2003).

Twilight Imaging. When the atmosphere is clear at night near the terminator, the NA camera can provide spectacular images in the absence of sunlight, owing to scattering of light over the horizon, through the martian atmosphere. The effect is especially enhanced when the surface is covered by bright, seasonal frost. Twilight images are usually acquired as downlink filler on orbits where realtime coverage is available but the terminator has not yet been crossed; however, some realtime images are targeted for a specific science purpose. For example, monitoring of seasonal frost from twilight to dawn as winter draws to a close shows the timing of the onset of dark, defrosting spots.

Wide Angle Camera Toolkit: *Daily Global Map.* The most important WA product is the daily global map. Each day, the WA cameras cover all of Mars in 12–13 orbits, providing a snapshot of weather events and seasonal frost. The record since March 1999 is nearly continuous at 7.5 km/pixel and provides unprecedented, diurnal and multi-year tracking of meteorological events and processes.

Context Images. Full-resolution (240 m/pixel) WA images (usually red) of 480 by 480 pixels provide context for NA images. Their purpose is to: (a) determine, independently of reconstructed spacecraft pointing information, where on Mars a NA image is located, and (b) to observe clouds, frost, or dust storms that may have reduced the quality of a given NA image. In areas where many context images overlap (*e.g.*, the poles; MER landing sites), they also provide a record of local albedo pattern changes over the course of the MGS mission.

Targeted Wide Angle Images. The WA cameras, like the MOC NA, can also be targeted to meet specific science goals. These include images to (a) monitor dust-raising events such as the large dust devils of northern Amazonis Planitia [3], (b) observe forecasted cloud and storm events, particularly dust storms known to repeat from year to year [3], (c) monitor changes in albedo patterns and wind streaks, (d) document interannual and intra-seasonal changes in seasonal frost patterns, (e) observe the martian limbs to help estimate cloud heights, and (f) obtain stereo (3-D) views at 240 m/pixel for topographic/morphologic studies.

MOC Data: MGS MOC data are archived with the NASA Planetary Data System (PDS) every 6 months, usually around 1 October and 1 April of each year. The labor-intensive archiving process ensures preservation of the highest quality product. Over 134,000 MOC images were archived as of October 2003; these can be viewed in the MOC Gallery at **http://www.msss.com/moc_gallery/**.

Reference: [1] Malin M. C. et al. (1992) *JGR, 97(E5),* 7699–7718. [2] Malin M. C. and Edgett K. S. (2001) *JGR, 106(E10),* 23429–23570. [3] Cantor et al. (2001) JGR, 107(E3), 5014, doi:10.1029/2001JE001588.