THREE DECADES OF MARTIAN SURFACE CHANGES. Paul E. Geissler, U.S. Geological Survey (2255 N. Gemini Drive, Flagstaff, AZ 86001 USA; pgeissler@usgs.gov).

Summary: The face of Mars has changed dramatically during the three decades spanned by spacecraft exploration. Comparisons of Mars Global Surveyor images with Viking and Mariner 9 data suggest that more than one third of Mars' surface area has brightened or darkened by at least 10%. Such albedo changes could produce significant effects on solar insolation and the global circulation of winds on Mars.

Background: Many surface changes were documented between the Mariner and Viking missions and from one year of the Viking mission to another [1-8]. Most of these changes were produced by aeolian activity, through deposition and erosion of dust or transportation of sand. Because of the short time span of the earlier observations, it was difficult to determine which of the changes were seasonal variations and which were long-term alterations. In many cases, owing to the lack of high-resolution data, the precise causes of particular albedo changes were uncertain. The nature and implications of martian surface changes were not clear.

New data from the Mars Global Surveyor (MGS), Mars Odyssey and Mars Express missions help clarify the causes and extents of martian surface changes. For this study we have used MGS Mars Orbiter Camera (MOC) daily global color images from the Wide Angle Camera (WAC) to monitor the appearance of the martian surface for the period from April, 1999 to January, 2003. These data enable us to estimate the present day normal albedo of Mars under the clearest atmospheric conditions, distinguish albedo changes over the past two martian years, and map longer term surface changes from the Viking and Mariner 9 eras to the present.

Approach: More than 1,000 WAC color images have been processed so far, a small fraction of the data available. These have been assembled into 14 global mosaics spanning two martian years. Each mosaic is the average of observations from several martian days. The individual images were corrected for limb-darkening using a wavelength-dependent Lunar-Lambert function. The zero-phase "hot spots" were omitted from the averages. The present procedure produces low-resolution mosaics of acceptable quality, but the results can be improved through better calibration and more sophisticated photometric corrections.

Construction of a cloud-free, summertime mosaic was achieved by combining the darkest pixels of the 14 mosaics taken at different seasons into a single color picture. Seasonal differences in overall brightness from one mosaic to another were first removed by normalizing the brightness of all the red and blue mosaics at low latitudes unaffected by the polar hoods.

Seasonal Changes: The first step in the analysis is to make a "movie" of Mars and observe its appearance as it changes throughout the martian year. All of the observed seasonal variations could be ascribed to atmospheric effects or surface frost. The growth and retreat of the polar caps, the appearance and disappearance of polar hoods, and the occurrence of equatorial clouds atop the volcanoes were much as predicted from decades of Earth-based observations [e.g., 9]. The great basins of Hellas and Argyre brightened during southern hemisphere winter due to deposition of surface frosts. Surface contrast was reduced during periods of high atmospheric dust opacity, as expected. No periodic changes in surface albedo boundaries were detected.

MGS to MGS Changes: Mars underwent a major global dust storm during the period from June to August, 2001 [10]. This storm produced several minor episodic changes, including brightening (presumably due to dust deposition) along the west margin of Syrtis Major (near 18 N, 300 W), portions of Nilosyrtis (40 N, 280 W), northeast of Hellas (27 S, 270 W), and to the northwest of Elysium (32 N, 235 W). Other areas darkened during the dust storm, perhaps through removal of dust by unusually strong winds: darkening occurred near the boundary between Hesperia and Elysium (7 S, 235 W) and at Sinai Planum (16 S, 90 W) which reverted to its former Viking-era appearance.

Viking to MGS Changes: Much greater changes were seen over the 20 year interval between Viking and MGS. Surface changes were identified by subtracting the Viking color digital image mosaic [11, McEwen] from the cloud-free, summertime MGS mosaic. Independently, these interpretations can be corroborated by comparison with the difference between the MGS Thermal Emission Spectrometer (TES) broadband albedo [12] and the Viking IRTM albedo [13], derived similarly.

Southern High-Latitude Band. The largest region that altered in appearance is a broad band of the southern highlands that extends southwards from about 40 S to at least 60 S, an area of some 40 million km^2. Both the MOC vs. Viking imaging and the TES vs. IRTM albedo data show that this region darkened during the past two decades. HST observations [14, Bell et al 1999] indicate that the change took place prior to 1995. In several places the northern margin of this band corresponds to the boundary between saturated and unsaturated laser returns in MOLA roughness maps [15].

Nilosyrtis. Large areas of the northern hemisphere high latitudes also darkened. Imaging observations show that the dark, circumpolar ring north of latitude 50 N enlarged markedly, affecting an area of more than one million km^2. In this case it is obvious that the albedo boundaries that divide bright from dark regions have shifted southwards, particularly at the classical albedo feature Nilosytis (43 N, 275 W) where TES and IRTM data indicate that the surface albedo dropped by up to 50%.

Alcyonis/Thoth. A much smaller area (161,000 km^2) darkened when the classical albedo feature Alcyonis or Thoth (30 N, 265 W) enlarged. Like many other low-latitude surface changes, the darkening of Thoth took place on a sloping surface with relatively high TES thermal inertia [12] and high IRTM rock abundance [16], suggesting that a thin veneer of dust was stripped off a bedrock surface during periods of high winds.

Hyblaeus/Aetheria. This classical dark albedo feature (at 25 N, 235 W) brightened and a new dark patch appeared to the east, affecting an area of about 1.2 million km^2.

Cerberus. This classical dark feature (10 N, 205 W) almost disappeared, except for a few dark patches emanating from Cerberus Rupes. The (probable) new dust deposits mantled an area of nearly 390,000 km^2.

Mare Sirenum. The darkening of the area near 30 S, 190 W may be an extension of the southern high-latitude band. Nearly 1.8 million km^2 grew noticeably darker, reducing the albedo of this region by 21% to 36%.

Propontis. An area of about 190,000 km^2 darkened in Acidalia Planitia near 37 N, 185 W. This change took place within a low, flat plain with moderate TES thermal inertia and IRTM rock abundance.

Aonis Sinus. The largest brightening suggested by the TES albedo took place at Daedalia Planum on steeply sloping terrain near the southwest end of Tharsis (30 S, 130 W). TES measurements suggest that an area of 2.2 million km^2 brightened, whereas the MOC images give a smaller figure of 1.2 million km^2.

Syria-Sinai-Solis Planum. MOC images taken after the 2001 dust storm show that the entire plateau south of the Valles Marineris (centered at 20 S, 90 W) darkened, affecting an area of 3.1 million km^2. The TES measurements and earlier MOC images (prior to the dust storm) indicate that Syria Planum was mantled by dust at the start of the MGS mission.

Acidalia. This dark feature enlarged along its margins, especially at 35 N, 30 W, and a new bright fringe appeared along its eastern edge. MOC images suggest an area of 2.2 million km^2 was affected, however TES albedo measurements suggest a much larger area of up to 4.6 million km^2 may have altered.

Pre-Viking Changes: Many of the surface changes described above were preceded by activity prior to 1978. Mariner 6 and 7 images show the Hyblaeus albedo feature absent, similar to its appearance in the MGS era [17]. Changes in the Nilosyrtis region began between Mariner 9 and the arrival of the Viking spacecraft. Cerberus also darkened and enlarged between 1972 and 1978 [18].

Discussion: Martian surface changes reveal the distribution of depositional and erosional zones under present winds and give important clues to the nature of surface materials. High-resolution MOC Narrow Angle Camera images so far give no indications that any of the changes are caused by mobile dark sands, suggesting that the albedo changes are instead dominated by deposition and erosion of dust. This interpretation is consistent with the observation that the albedo changes generally take place on sloping surfaces with medium to high thermal inertia and rock abundance. Several sites such as Hyblaeus, Cerberus and Sinai seem to alternate between high and low albedo as thin mantles of dust are deposited and later stripped off. Thus despite the dramatic changes seen over the last 30 years, the face of Mars likely returns to an equilibrium or average appearance over the longer term.

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