Planetary Sciences

P51A MCC: Hall D Friday 0830h

Martian Dust Devils: Observations, Simulations, and Terrestrial Analogues Posters *(joint with A)*

Presiding: **M Balme,** Arizona State University**; N O Renno,** University of Michigan

P51A-0331 0830h POSTER

Martian Dust Devils: 2 Mars Years of MGS MOC Observations

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Mars Global Surveyor (MGS) Mars Orbiter Camera (MOC) wide and narrow angle images have captured more than 1000 active dust devils over 2 Mars years. In the most recent Mars year, we repeatedly imaged (and are continuing to image) several areas to monitor dust devil occurrence. Some Mars dust devils are as small as a few to 10s of meters across, others are 100s of meters across and over 6 km high. Each Martian hemisphere has a dust devil season that generally follows the subsolar latitude. An exception is NW Amazonis, which has frequent, large dust devils throughout northern spring and summer (probably every afternoon; observations are acquired 2-3 times a week). The Amazonis and other MOC observations show no evidence that dust devils cause, lead to, or have a systematic relationship with dust storms. However, dust devils sometimes do occur near small, localized storms; and one specific relation occurred during the onset of the global dust events of 2001: slightly elevated levels of atmospheric dust (an optically thin cloud) triggered a very short period of dust devil activity in NW Amazonis in early northern autumn. The redistribution of dust by the 2001 global events may have also affected subsequent spring and summer dust devil activity in Hellas, where considerably fewer dust devils occurred in 2001-2002 than 1999-2000. In SW Syria, frequent, large dust devils occurred after the 2001 global events and persisted through southern summer. While dust devils have no specific relation to dust storms, they might play a role in the seasonal wave of darkening at middle and high latitudes by removing or disrupting thin veneers of dust. Dust devils have been observed to create thin, filamentary streaks. Some streaks are darker than their surroundings, while others are lighter. Some dust devils do not create streaks. At mid-latitudes, surfaces darken in spring as 100s of crisscrossing streaks form on widely-varied terrain. Some rare streaks exhibit cycloidal patterns similar to those created on Earth by tornadoes with multiple sub-vortices. The streaks occur at nearly all latitudes and elevations, from north polar dunes to the south polar layered terrain, from the summit of Olympus Mons to the floor of Hellas. During dust devil season at a given latitude, tremendous changes in streak patterns occur in periods as short as 1 month. These observations, along with repeated imaging in NW Amazonis and SW Syria, provide some idea of the frequency of dust devils. Uncertain is whether dust devils are responsible for all thin, filamentary streaks: while active vortices have been seen creating the plethora of streaks at southern mid-latitudes, none have been observed on the northern plains, despite observation of similar streak patterns. Perhaps northern plains dust devils occur at a different time of day relative to the MGS 1400 LT orbit, or perhaps dust devils did not form them. We monitored removal of dust from surfaces after the 2001 global dust events in several locations. Of particular interest was western Syrtis Major, which had brightened considerably after the 2001 storms. We observed this area for several months while very little change occurred. Finally, in January 2002, the surface was swept clean of most of its 2001 veneer of dust in a period of about 1 week. Dust devils played no role in this process; instead, regional surface winds were responsible.

P51A-0332 0830h POSTER

A Survey of Martian Dust Devil Activity Using Mars Global Surveyor Mars Orbiter Camera Images

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We present results from an orbital survey of Martian dust devils using the Mars Global Surveyor (MGS) Mars Orbiter Camera (MOC) wide- and narrow-angle (WA and NA) images. The survey includes all available imaging data (mapping and pre-mapping orbit), through to mission phase E06. Due to the large volume of data, we have concentrated on surveying limited regions, selected variously on the basis of where dust devils or other dust storm activity has previously been reported, on the basis of where lander observations have been or will be obtained, and on the basis of predictions from numerical atmospheric models. Our study regions to date include: Amazonis Planitia (25-45N, 145-165W), Sinus Meridiani (10S-10N, 10E-10W), Chryse Planitia (10-30N, 30-60W), Solis Planum (15-45S, 75-105W), Hellas Planitia (15-60S, 265-315W), Casius (45-65N, 255-285W), Utopia Planitia (25-45N, 225-255W), Sinai Planum (10-20S, 60-100W), Mare Cimmerium (10-45S, 180-220W). We have compiled statistics on dust devil activity in three categories: dust devils observed in NA images, dust devils observed in WA images, and dust devil tracks observed in NA images. For each region and each category, we have compiled statistics for four seasonal date bins, centered on the equinoxes and solstices: Ls=45-135 (northern summer solstice), Ls=135-225 (northern autumn equinox), Ls=225-315 (northern winter solstice), and Ls=315-45 (northern spring equinox).

Our survey has highlighted great spatial variability in dust devil activity, with the Amazonis Planitia region being by far the dominant location for activity. This region is additionally characterized by a large size range of dust devils, including individual devils up to several km in height. Other regions in which dust devils have been frequently imaged include Utopia, Solis, and Sinai. Numerous dust devil tracks were observed in Casius and Cimmerium, but with very few accompanying dust devils. This suggests dust devils occurring in local times other than that of the MGS orbit (2pm). Our seasonal statistics suggest a very strong preference for Amazonis and Solis dust devil activity to occur in the northern autumn season. Conversely, Utopia shows dust devil activity which is relatively constant, except in the northern spring period.

The observations will be presented, and compared with numerical model predictions. Initial results from this survey have already been used to define target regions for very high resolution simulations of dust devil development using the Caltech/Cornell Mars MM5 model.

P51A-0333 0830h POSTER

Simulation of the Martian Boundary Layer and Dust Devils With the Mars MM5 Mesoscale Atmospheric Model

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The observed year-to-year repeatability of Martian atmospheric temperatures and dust opacities in northern spring and summer suggests that the seasonal cycle of Martian atmospheric dustiness cannot be explained uniquely in terms of large (regional and global scale) dust storms. Instead, a steady source of atmospheric dust is needed that generates a seasonal supply pattern that is essentially repeatable. Dust devils have been widely suggested to operate in this role. Theoretical studies to date have mainly focused on analytical models of dust devils as thermodynamic and dynamic systems. In this presentation, we discuss three-dimensional, numerical simulations of the Martian convective boundary layer, and specifically convective vortex/dust devil development. The simulations are undertaken with the Mars MM5 mesoscale atmospheric model developed at Caltech and Cornell University. The model is nonhydrostatic, and employs parameterizations for heat diffusion in the Martian subsurface, radiative heating due to dust and carbon dioxide gas in the visible and thermal infrared, radiatively and dynamically interactive dust, and (where applicable) the cycling of carbon dioxide and water between the surface and atmosphere. In these simulations of the Martian boundary layer, the model is used with a horizontal grid spacing of 20 to 100 m, and with a minimum of 100 points in each direction, and over 50 levels in the vertical direction. We initially simulate a region near the equator, with surface properties characteristic of the Sinus Meridiani ("Hematite") region and for mid southern summer. We also show simulations for a location in the northern tropics and with surface properties consistent with the Amazonis Planitia region. These simulations are conducted near southern spring equinox, a time when Mars Orbiter Camera (MOC) images suggest development of copious, massive dust devil structures. In all cases, we find evidence for the development of convective, vertically aligned vortices. We will discuss the nature and behavior of the various vortices developed in the simulations.

P51A-0334 0830h POSTER

Vortex Threshold: Experimental Results at Martian Atmospheric Pressures

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Many examples of Martian dust devils and tracks left by their passage have been identified in Viking and Mars Orbital Camera images and inferred from lander data (Viking and Mars Pathfinder). Recent surveys suggest that dust devils may be common phenomena on Mars and, unlike Earth, could contribute significantly to the global dust budget.

Previous studies have noted the apparent paradox that Martian airborne dust is abundant and only a few microns in diameter yet experiments at Mars pressures suggest current Martian ambient wind speeds are insufficient to lift such fine particles from the surface; speeds of the order of 10s or even 100s of m/s are required. Local wind speeds within terrestrial dust devils are typically much greater than ambient wind speeds, but we have no in-situ measurements of the velocity structure of Mars dust devils and so cannot directly quantify their ability to entrain material. However, by using laboratory simulations we can directly measure the ability of a vortex to lift material of known size and density under a variety of atmospheric pressures.

We have constructed a vortex generator consisting of a large vertical cylinder containing a rotor comprising four vertical blades and capable of speeds up to 4500 RPM. Beneath the cylinder is a 2.4 by 2.4 m tabletop which can be covered in particles for threshold tests or instrumented with pressure transducers to measure the pressure structure of the vortex. The distance between the cylinder and the tabletop and the height of the blades within the cylinder can be varied to generate a wide range of geometries and intensities of vortices. Recently, the apparatus has been operated at the NASA-Ames Research Center Mars Surface Wind Tunnel facility to simulate Martian atmospheric conditions.

We have measured vortex saltation threshold using many types of particles ranging in density from walnut shells (1.1 kg/m^{-3}) to steel grit (7.6 kg/m^{-3}) with particle sizes from 2 to 2000 microns and using atmospheric pressures ranging from 10 mbar (representing current Mars atmospheric conditions) to ambient. As expected, vortex threshold was more difficult to achieve with lower pressure conditions. Only the optimum particles (those with low densities and particle sizes ranging from 70 to 350 micron) reached full saltation at 10 mbar pressure before the apparatus speed limit was reached.

Our results suggest that vortex threshold is directly analogous to boundary layer shear threshold for sand-sized particles at pressure from 65 mbar to ambient. We have used this result to equate vortex and boundary layer results in the sand-sized particle regime and hence to compare vortex threshold data with boundary layer results for smaller particles and lower pressures. We used empirical boundary layer expressions for threshold (corrected for particle size and particle Reynolds number). In all cases, vortex action appears more efficient than boundary layer winds at lifting small dust-sized particles and at lifting all particles at very low pressure.

We conclude that Martian dust devils are more efficient mechanisms for particle entrainment than boundary layer winds, not merely because they have enhanced local wind speeds but also through another intrinsic mechanism. We suggest that a lift force caused by the passage of the low-pressure core of the dust devil over the particles would have such an effect and present examples of experimental pressure-well measurements at low pressures to support this.

P51A-0335 0830h POSTER

The Electrical Structure of Terrestrial Dust Devils: Implications of Multiple Vertical Measurements of the Electric Field

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In this work we discuss observations of the electrical structure of dust devils made in the summer of 2001 and 2002 during the Mars Atmosphere and Dust in the Optical and Radio (MATADOR) field campaign outside of Tucson, Arizona. While it has long been known that Terrestrial dust devils can support large electric fields of magnitudes of up to 10 kV/m or more, the fundamental features of the charging mechanism have yet to be fully characterized from an observational perspective. If triboelectric charging is indeed responsible for the generation of significant electric potentials within the dust column, some means of large scale stratification and/or separation of charges is necessary to maintain these fields. To help address this question and elucidate the overall vertical charge distribution of dust devils, we used two field mill instruments to make simultaneous measurements of electric fields both at the surface and 1 meter above the ground. At present, our observations indicate that the dust grains become negatively charged at or very near the air-surface interface. The largest devils recorded (30 m diameter) show a region of enhanced positive electric fields persisting for minutes after the event has passed, indicating the possible presence of a large scale collection of airborne positive charges following the negatively charged dust column. Based on our observations, the key to the charging mechanism appears to reside in the bottom of the saltation layer where the bulk of collisional frictional charging is likely to occur. We discuss the implications of these observations for theories of Terrestrial dust devil electrification and for our understanding of similar processes on Mars.

P51A-0336 0830h POSTER

Quantification of Charge in a Dust Devil based on its ULF Magnetic Signature

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In summers of 2000, 2001 and 2002, three separate desert campaigns took place to study the fluid and electrodynamic nature of dust devils. One surprising new result from these intense studies is the discovery of a ULF magnetic signature associated with the devils. In this paper, we will discuss the observations of the low frequency magnetic activity and quantify the amount of dust devil tribocharging required to obtain the signal, treating the devil as a radiating solenoid. This charge density will be compared to that derived based on the electrostatic fields. We demonstrate that dust devils are very active charge generators, creating charge densities comparable to the terrestrial ionosphere. Implication for similar processes at Mars will be discussed, including the charged dust devil effects on electric-sensitive equipment.

P51A-0337 0830h POSTER

Simulation of Amazonis Planitia Summer Convection

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Numerous large dust devils have been repeatedly observed by Viking and MGS MOC during the summer season in northern Amazonis Planitia. The presence and size of these vortices strongly suggests that the daytime atmosphere over the region vigorously convects at this season. Of course, the convection itself is intangible to spacecraft. The Mars Regional Atmospheric Modeling System (MRAMS), a mesoscale numerical model, can provide the linkage between such observed phenomena and those that are invisible. The MRAMS simulation presented here provides a three-dimensional view of how the atmosphere over Amazonis Planitia evolves with time (about 0.5 sol) and interacts with mesoscale surface features (e.g., ridges, craters) and atmospheric phenomena (e.g., katabatic flows from Olympus Mons, topography-induced gravity waves). These results are also compared to information derived from the MOC dust devil images.

P51A-0338 0830h POSTER

Laboratory Experiments on Electrostatic Discharging in Martian Dust Devils and Dust Storms

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Due to the prevalence of Martian dust devils and dust storms, an understanding of the underlying physics of electrical discharges occurring in Martian dust is critical to future Mars exploratory missions. When dust particles come into contact, charge can be transferred between the grains. Wind driven dust studies (Weather, 1969) show that in the case of particles with identical compositions, the particle with the larger radius in a collision preferentially becomes positively charged. The stratification of particle sizes generated by upwinds within a dust cloud causes an electric dipole to form. When the electric potential within the cloud exceeds the breakdown voltage of the surrounding atmosphere, a discharge occurs.

Mars' low atmospheric pressure and arid, windy environment suggest that the dust near the surface of Mars is even more susceptible to triboelectric charging than terrestrial dust. Electrical discharges on Mars should occur more frequently but at lower intensities than those seen on Earth.

We have conducted laboratory experiments to examine the creation of discharges due to horizontal mixing and vertical charge separation in a simulated Martian environment. The range of pressures and the amount of mass loading required to produce these discharges have been examined. Measurements done in our lab on the charging of single dust grains show that particles of JSC-Mars-1, a Martian regolith simulant, can have large electrical potentials due to triboelectric charging. When JSC-Mars-1 is stirred or vertically dropped in a low-pressure CO_2 atmosphere, electrical discharges are both visually and electronically detected. Measurements of the frequency and intensity of these discharges show that they can occur under conditions expected on the Martian surface.

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P51A-0339 0830h POSTER

Mars Dust Threshold Under Heated Surface Conditions

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A wind tunnel was used to study the effects of a heated surface, thereby creating an unstable near-surface atmosphere, on the threshold of aeolian-blown (windblown) dust-size particles (1-2 mm) under Mars-simulated pressure. Unstable conditions on Mars typically arise during the mid to late afternoon hours due to the accumulation of daytime solar-radiation. When the surface is warmer than the atmosphere just above it, vertical turbulence is increased. Thus, loose dust particles can be more easily lofted and mixed at a threshold wind speed lower than that known under neutral atmospheric conditions. For this wind-tunnel study, unstable (heated) surface conditions were simulated based on the negative temperature gradients and surface bulk Richardson numbers estimated from the Mars Pathfinder Lander (MPL) mission data during the mid-afternoon to early evening Mars period. According to other missions, evidence of highly active dust suspension during this part of the Mars daytime hours was recorded, including the presence of "dust devils". Experiments were performed in the Martian Surface Wind Tunnel (MARSWIT) located at NASA Ames Research Center, Moffett Field, California. Based on data acquired from the MPL site, the mean surface pressure was found to be 6.75 mb. Thus, simulations in MARSWIT were conducted at 10-mb atmospheric pressure using air, which agrees with a dynamically similar environment of 6.5 mb on Mars. In order to attain the necessary vertical temperature gradients that would develop an unstable layer, a test bed was heated by subsurface heaters. Three surface roughness conditions were simulated, over which not only dust threshold was measured but also velocity and temperature profiles were acquired under various heating levels. Boundary layer measurements and analysis conducted under neutral conditions were used to estimate roughness height, zo, and the friction speed, u*, for all stability conditions. Dust threshold tests were conducted using a surrogate Mars soil, Carbondale Red Clay (CRC), which has a mean particle diameter of about 1 to 2 mm in dust form. According to boundary-layer analysis, two test beds, having zo = 0.015 mm and 0.09 mm, generated hydraulically smooth-wall turbulent flow. Under neutral stability conditions, the corresponding dust threshold frictions speeds for these two surface conditions were u* = 1.63 m/s and 1.61 m/s, respectively. Heated-surface experiments also showed that the two smoother test beds developed a decreasing trend in threshold wind speed, from 30 m/s at neutral conditions to 8 and 20 m/s, respectively, at increased surface heating levels. A third bed, zo = 0.018 mm, observed the classical rough-wall "law-of-the-wall" trend. This rougher test surface, however, portrayed the opposite effect, where threshold increased for greater instability conditions. The major difference between the first two smooth beds and this rougher bed was the application of conductive roughness elements (steel nuts), which initially caused a lower threshold value of u* = 0.77 m/s at neutral conditions, but then increased with higher surface heating. This latter result should be viewed as preliminary.

P51A-0340 0830h POSTER

Matador 2002 Field Test: A Pilot Experiment on Heat and Aerosol Transport by Dry Convection and Dust Devils

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Recent research suggests that mineral dust play an important role in the earth's climate by altering the atmospheric radiation budget and by affecting cloud microphysics and optical properties. Moreover, dust can act as a catalyst for reactive gas species in the atmosphere and can influence photochemical processes. Many studies have shown that, on a micrometeorological scale, dust sourcing is sensitive to a large number of factors such as soil composition and moisture content, vegetation cover, topography, and weather.

Dust devils are frequently observed over terrestrial deserts and are ubiquitous features of the Martian landscape. These small convective vortices play an important role in the vertical transport of mineral dust and heat, both on Mars and on earth. Charge separation within their "dust clouds" produce strong electric fields, which can ionize the thin Martian atmosphere and might have important implications for its chemistry. Moreover, terrestrial dust devils are a hazard to

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general aviation, while Martian dust devils are potentially harmful to spacecraft Landers.

Our group has been conducting field projects to understand the electrification of dust devils and the contribution of dry convection and dust devils to the vertical transport heat and aerosol (mineral dust). Our initial results show that dust devils produce heat fluxes that are about two orders of magnitude larger than the background ambient flux. Indeed, it suggests that most of the vertical heat transport in active convective layers is done by coherent convective plumes. We will discuss our measurement techniques and summarize our most important results.

P51A-0341 0830h POSTER

Field Studies of Very-Near Surface Dust Devil Processes

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This work continues a long term research program into the fundamental very near-surface processes of dust devil vortices, especially in support of the ASU Vortex Simulator, as well as landed Martian missions such as MER and the Mars Express Beagle 2. Field experiments conducted in southern Nevada chased and directly sampled over 40 vortices with a profiling instrument array that extended down to the desert floor. Pressure, temperature, and horizontal/vertical wind speed and direction sensors reveal a complex microenvironment operating at the base of these thermal vortices. Preliminary analysis indicates that vortex inflow is stratified and fluctuates rapidly in a manner that contributes substantially to soil erosion and upward transport. Our report will characterize vortex dynamics and relate them to observed surface geologic and aerodynamic conditions as determined by complementary in-situ wind tunnel studies, among others.

P51A-0342 0830h POSTER

Measurements of Dust Devil Lower Structure and Properties, El Dorado Valley, Nevada, June 2002

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We report the results of a recent field campaign in Nevada, USA, carried out to investigate the lower structure (less than 2m) and dust lofting mechanisms of terrestrial dust devils. Over several days, an instrumented platform was repeatedly deployed from the back of a pickup truck into the path of oncoming dust devils. Around 40 events were recorded, including core penetrations of large and small dust devils, close misses and periods of ambient background conditions before and after dust devil events, and during periods of dust devil inactivity. The platform deployed consisted of a 2 by 1m base with a 2m mast and carried a total of 24 instruments. The instrument suite consisted of horizontal wind profiling down to 5mm above surface, vertical wind speed and direction, temperature and pressure profiling, airborne and saltating particle recorders, vertical electric field gradient measurements, and upward looking UV sensors. We present preliminary results of profiles for several events, together with details of ambient conditions required for dust devil formation.

P51A-0343 0830h POSTER

Dust Devil Track Occurrence in Argyre Planitia.

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Martian dust devil tracks were first observed in Viking Orbiter images [Thomas et al., 1985]. While the interpretation of these features was at first controversial, it is now widely accepted that the tracks are formed by the passage of small convective vortices (dust devils). As the dust devils travel across the surface the atmosphere is loaded with fine particles creating a visible trail inferred to be removal or deposition of material [Greeley et al., 2001].

Mars Global Surveyor (MGS) Mars Orbital Camera (MOC) images of dust devil tracks in Argyre Planitia were used to asses dust devil track abundance as a function of Martian season as well as elevation using Mars Orbiter Laser Altimeter (MOLA) data. Argyre Planitia is a large impact basin in the southern hemisphere (55° to 33°W and 35° to 58°S), with topographic relief of 7 km with the median at 1km. We have studied the 564 Narrow Angle MOC images (taken as of summer 2002) covering the area. The images were divided into two categories: those with devil tracks and those without. The Ls (solar longitude degrees as a fraction of orbit) and elevation of all of the images with and without devil tracks were noted. The elevation was recorded at the center point of each MOC image using MOLA data.

A polar plot of all of the images shows a statistically random distribution throughout the Martian year. A context map of the images shows a representative distribution over the area of the crater itself. A polar plot of dust devil track occurrence within the area observed shows a major concentration of tracks between Ls 200° and 360° (southern spring to late summer). A seasonal breakdown of devil track occurrence as a percentage of total area observed yields: fall 11.25%, winter 2.24%, spring 27.21%, and summer 46.49%. We therefore conclude that dust devils tracks are formed preferentially in summer and are destroyed, fade or are covered, over a period of a few months.

The elevation of all 564 images was measured and 1km bins were used to calculate the percent of occurrence. We discovered that, at 3km 0% of the observed area contain dust devil tracks, 2km 7.69%, 1km 12.90%, at Datum 15.95%, 1km 8.97%, -2km 28.92%, -3km 50.00%, -4km 50.00%. Independent of the season a majority of the devil tracks were observed below 3km. Therefore elevation is a key factor governing the formation of dust devils or their ability to produce tracks.

Our interpretation of these results is that dust devils are much more likely to form during the summer and, as suggested by recent experiments [Balme et al., 2002], that they are more efficient at moving materials on the surface in areas where the atmospheric pressure is greatest (in the lowest elevations). The short timescale for disappearance of tracks suggests that the distinct albedo variations of the tracks result from only the removal or deposition of a very thin layer of material.

Thomas. P. et al., 1985, Science v. 230 Greeley. R. et al., 2001, LPSC XXXII Balme. M. et al., 2002, LPSC XXXIII

P51B MCC: Hall D Friday 0830h

Mystery of the Martian Rivers Posters *(joint with C, H)*

Presiding: **O B Toon,** University of Colorado**; T Colaprete,** NASA Ames Research Center

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The Valley Networks on Mars

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Despite three decades of exploration, the valley networks on Mars still seem to raise more questions than they answer. Valley systems have formed in the southern highlands, along some regions of the dichotomy boundary and the south rim of Valles Marineris, around the rim of some impact craters, and on the flanks of some volcanoes. They are found on some of the oldest and youngest terrains as well as on intermediate aged surfaces.

There is surprisingly little consensus as to the formation and the paleoclimatic implications of the valley networks. Did the valleys require a persistent solar-driven atmospheric hydrological cycle involving precipitation, surface runoff, infiltration and groundwater outflow as they typically do on Earth? Or are they the result of magmatic or impact-driven thermal cycling of ground water involving persistent outflow and subsequent runoff? Are they the result of some other process(es)? Ground-water sapping, surface-water runoff, debris flows, wind erosion, and formation mechanisms involving other fluids have been proposed. Until such basic questions as these are definitively answered, their significance for understanding paleoclimatic change on Mars remains cloudy.

I will review what is known about valley networks using data from both past and current missions. I will discuss what we have learned about their morphology, environments in which they formed, their spatial and temporal associations, possible formation mechanisms, relation to outflow channel and gully formation, as well as the possible implications for past climate change on Mars. Finally I will discuss how future, meter to submeter scale imaging and other remote sensing observations may shed new light on the debate over the origin of these enigmatic features.

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Greenhouse Models of Early Mars Climate

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Nearly all authors agree that Mars early (pre-3.8 Ga) surface was wet, as evidenced by many signs of flowing water on its heavily cratered southern highlands. Exactly what this implies about the early martian climate is a topic of ongoing debate. Some authors (1) have argued for a warm, nearly Earth-like climate; others (2) have suggested that the mean surface temperature could have been significantly below freezing. Here, I argue that the wetter early Mars was, the higher its mean surface temperature must have been in order to create the observed fluvial features. A planet with a large ocean, like Earth, would need to have a mean surface temperature at or above 0oC in order to avoid freezing over entirely. For a low-obliquity planet like Earth, ice albedo feedback causes the climate to become unstable when the polar caps extend equatorward of 30o (3). Mars has a highly variable obliquity, but the same reasoning is still likely to apply.

If, indeed, Mars had an Earth-like early climate, then it must have had a substantial atmospheric greenhouse effect. Solar luminosity increased from about 70 percent of its present value at 4.6 Ga to 0.75 times present at 3.8 Ga (4). Gaseous CO2-H2O atmospheres can produce surface temperatures no higher than 225 K during this time (5). Radiative heating by CO2 ice clouds might raise this temperature somewhat (6). Obtaining surface temperatures above freezing with this mechanism, though, requires nearly 100 percent cloud cover, which is highly unlikely for condensation clouds. A methane greenhouse is a more attractive mechanism. The combination of a few bars of CO2, along with a few tenths of a percent CH4, could have kept early martian surface temperatures above freezing. This would probably have required a biogenic source for methane, however, as abiogenic sources are unlikely to have been strong enough to maintain such concentrations in the face of photolysis by solar UV radiation. Although admittedly speculative, such a mechanism could explain the fluvial features that we see today.

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Carbon dioxide clouds in an early dense Martian atmosphere

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We use a time dependent, microphysical cloud model to study the formation of carbon dioxide clouds