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Editorial

Dynamic Mars from long-term observations: Introduction

Of all the planets in the Solar System besides Earth, Mars stands out as one for which both surface and atmospheric changes occur at decadal, annual, and shorter time scales. Indeed, the seasonal variability of Mars was noted by early astronomers such as Herschel, Schiaparelli, and Lowell. With the advent of the space age, Mars has been of particular focus for exploration. Beginning with Mariner 4 in 1965, no fewer than 20 successful spacecraft have flown by, orbited, landed, and roved on the surface. Although this exploration has been heavily driven by trying to understand the role of present and past water on the planet, and the search for evidence for environments that could support life, data from all these spacecraft has led to numerous discoveries spanning geology, geophysics, atmospheric sciences, and other fields.

The period of martian exploration we find ourselves in now is unique, as there has been a continuous record of spacecraft exploration that began with Pathfinder and Mars Global Surveyor in 1997. Now well into the 2nd decade of this campaign, bridged to earlier times by spacecraft observations from the 1960s and 1970s, and continuous telescopic observations, our view of Mars has become one of a planet on which surface and atmospheric changes occur at frequencies of days, years, and decades, a testament to long-term monitoring that continues to this day.

Recognizing this accumulation of data and an emerging view of Mars as a dynamic planet, we thought it an appropriate time that this record, with implications for martian geology, climate, atmospheric dynamics, and other processes, be integrated into a single journal special issue, presented here. This volume contains 20 papers each of which make use of one or more datasets and cover >1 Mars year. The papers highlight new results that are a unique outcome of the long-term data acquisition provided by our robust and long-duration program of Mars exploration and telescopic observations. The papers also highlight the long-term implications of processes that are observed and ongoing now, and show the importance of such longevity and consistency in atmospheric and surface observations. These results demonstrate the importance of continuous monitoring of Mars through new and especially extended missions.

We thank the authors, reviewers, and the editors, and especially Eva Scalzo at Icarus, without whom this special issue would not be possible. Eva, the editorial office manager for Icarus, was the interface between us and the reviewers and authors, and provided much-needed advice on policies and procedures. Jeff Moersch was the Icarus editor who oversaw this issue. He provided timely and sage advice on several reviews and questions concerning editorial policies. We would finally like to thank Phil Nicholson for granting permission for this special issue to proceed.

We summarize the contents of the special issue in the following sections.

1. Ionosphere

With the MAVEN spacecraft's arrival at Mars, our understanding of the martian ionosphere is sure to increase. These data can be compared and contrasted to studies such as two presented in this special issue by Withers et al. (2015) and Zhang et al. (2015), who make use of MGS and MEX observations to gain further insight into the long term (Withers et al., 2015) and transient (Zhang et al., 2015) behavior of the ionosphere. Using both MGS and MEX data, Withers et al. (2015) examine the peak electron densities in the Mars ionosphere and show that they increase smoothly with increasing solar irradiance throughout the >1 solar cycle of observations now available. They also see hints of trends possibly associated with seasonal variations in the martian thermosphere. Zhang et al. (2015) use the MEX/MARSIS data of the martian ionosphere to investigate transient layers that lie above the peak electron density layer studied by Withers et al. (2015). The height and density of the transient layer, typically 60 km above the main density peak, correlate with the height and density of the main peak. They find that in the southern summer, the transient layer is about 10 km higher than other times of year, likely resulting from lower atmospheric heating. They suggest that beam-plasma instabilities are responsible for the transient layers.

2. Lower atmosphere

The behavior of the water vapor, water–ice and dust aerosols, and temperatures in the lower atmosphere define the current climate and weather of Mars. This is, of course, critical for accurate modeling, deciphering the controlling physical mechanisms, and for understanding the past climate, when Mars may have been warmer and wetter and a hospitable place for life. Six papers in this special issue discuss these quantities and are summarized here.

As highlighted in this special issue, having a long record of observations from a variety of spacecraft with similar, yet different, techniques is very valuable in defining the climate of Mars and understanding differences due to weather. However a challenge is understanding the uncertainties in the different techniques and the cross-calibration between experiments. In 2015, Shirley (2015a) provides a comparison of atmospheric temperatures and aerosols between the MRO/MCS limb sounding experiment and

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limb profiles taken by the MGS/TES experiment, using MGS RS temperature profiles as a common standard for comparison. He finds good agreement when the opacities are similar, except at the highest TES sampled altitudes, when MCS temperatures are systematically higher, providing confidence in use of these data for long-term studies. Shirley (2015a) finds that there is some interannual variability in latitudinal temperature gradients, thermal tide behavior, and water–ice aerosols during the aphelion season.

Understanding the behavior of water vapor in the martian atmosphere is important for characterizing the present global water cycle, and for validating models, which can then be used to gain insight into the past martian climate. In this issue, Trokhimovskiy et al. (2015) provides new retrievals of water vapor from the MEX/SPICAM experiment covering 5 Mars years. His retrieval is improved by accounting for the multiple scattering of both dust and water–ice aerosols. He finds that the annual cycle is largely repeatable with water vapor maxima and minima consistent with other observational datasets. The exception is with MY 28 in which a global dust storm occurred. In this year, near the season of the storm, the water vapor abundances are lower than typical, which cannot be explained by masking by dust. Trokhimovskiy provides maps of water vapor abundance for each year, as well as maps showing retrieved saturation altitudes.

Dust in the martian atmosphere is important for controlling the dynamics of the planet, and its optical depth and spatial and temporal variations are needed for accurate modeling of the atmosphere. In particular, dust distribution and amount are needed to calculate the mass mixing ratio and the heating of the atmosphere, both of which are used to estimate the thermal forcing of the atmosphere for the given conditions. Montabone et al. (2015) provide a nearly 8-Mars-year dust climatology using 3 dust datasets: MGS/TES, ODY/THEMIS, and MRO/MCS (see cover illustration). They provide two types of gridded maps, irregular, which has missing data due to lack of coverage or poor data quality, and complete maps using kriging, an interpolation scheme. Maps showing both data sets are provided as online supplementary material and the datasets are available for download from the Mars Climate Database (MCD) website, referenced in their paper. Further, they have provided an average climatological year. Montabone et al. (2015) compare and quality check their results with dust optical depths from other orbital and landed instruments, including the MER Pancam and Mini-TES, the Phoenix SSI, MRO CRISM and MARCI, and the MGS MOC. Their work identifies and documents various instrument biases (compare to Shirley (2015a)). Examining their resulting climatology, they identify 4 annual phases of dust distribution, for years without a global dust event, consistent with Lemmon et al. (2015), Wang and Richardson (2015), and Kass et al. (2014).

To complement global, lower spatial resolution observations of dust optical depth, Lemmon et al. (2015) provides and archives to NASA's Planetary Data System the extinction optical depth record from both MER rovers (3 MY for Spirit; 5 MY for Opportunity). The data show that, for these two equatorial locations, the dust amount is low for the northern spring through mid-summer, with tens of percent variability year over year. Dust is more variable for the remainder of the year, being characterized by local, regional, and the occasional global dust storm, consistent with Montabone et al. (2015). Comparison with MER mini-TES contemporaneous observations at a different wavelength shows that the mean dust particle size is typically 1–1.4 μm, but becomes 2 μm at the onset of dust storms. This surface view of dust also allows for the study of smaller scale events, such as dust devils. Lemmon finds that insolation received at the surface (from seasonal changes and/or total optical depths) appears to control dust devil frequency at Spirit.

The origin and evolution of large-scale dust events, particularly, global dust events, is not well understood. As such, studies enabled by continuous global imaging covering multiple Mars years to examine many events are key to identifying characteristics and seasons of generation and evolution, as well as for quantifying behaviors that can be compared to models. This has been done in Wang and Richardson (2015), who examined daily global maps of aerosols over portions of 7 Mars years (12 Earth years) to identify and study large, discrete dust events that lasted $\geqslant$5 sols, and in which dust expanded outside the origination region. The daily global maps were created from data taken from the MGS MOC and the MRO MARCI instruments. They studied a total of 65 events, not including dust events that remained confined to the circumpolar regions. They identify that all events occurred between $L_s = 135–30°$, indicating a short dust-storm free season, consistent with lower optical depths seen in Montabone et al. (2015) and Lemmon et al. (2015). They define types of dust storm development, identify regions of dust storm generation, and provide a figure indicating the routes traveled by these storms. Of the two global events, they propose that both originated with southerly events, although the 2007 storm is somewhat ambiguous.

To further understand global dust storm origination, a new hypothesis has been proposed by Shirley (2015b). He provides an updated table of global dust events from 1924 to 2013, and argues that a statistically significant relationship between the storm occurrence and variations in the orbital angular momentum of Mars with respect to the Solar System barycenter exists, meaning that planetary dynamics may influence the interannual variability of the martian atmosphere. Further, Shirley (2015b) provides a prediction for future years that should experience global dust events, if this correlation persists, but cautions that other factors such as availability of dust supply in convenient reservoirs may be important in global dust storm manifestation.

3. Surface monitoring and dynamic processes

High scientific yields using data spanning years and across multiple spacecraft is aptly demonstrated in the 11 papers focusing on martian surface monitoring. These works include those on surface albedo changes, volatiles and ice, gullies, aeolian processes, and surface geology, with overlap in many areas. We give a brief overview of these papers here.

Albedo changes are the most obvious and pervasive responses to dynamic processes on Mars, namely the lifting, transport, and deposition of dust. Beginning with telescopic observations, albedo monitoring has continued to the present day with spacecraft data. On this topic, Vincendon et al. (2015) describe observations of surface albedo changes observed by Mars Express' OMEGA imaging spectrometer from 2004 to 2010. Using a detailed retrieval scheme, they find that bright surfaces are 17% greater than previous measurements, with most changes occurring during the storm season, in particular that of the 2007 global event. Changes over seasonal to decadal timescales are attributed to the removal and deposition of optically thin, bright dust coatings that mask underlying near-IR spectral signatures.

The presence, distribution, and dynamics of volatiles and ices control the martian energy budget and the atmospheric circulations, and reflect temperature-dependent phase changes that exchange carbon dioxide and water between the martian surface–subsurface and atmosphere. In this issue Piqueux et al. (2015a) document polar CO_2 cap recession/growth over MY 24 to 31 and define a "climatological" cap edge as a function of season. They use thermal IR data, insensitive to lighting conditions, and are therefore able to present for the first time the full growth/recession cycles for all 8 MY. Outside of the two global dust storm periods, they find that the north polar cap behavior is very