MARS METEOROLOGICAL NETWORK. H. L. Justh[1] and J. F. Spann[2], [1]NASA Marshall Space Flight Center (Mail Code: EV44, Marshall Space Flight Center, AL, 35812, Hilary.L.Justh@nasa.gov), [2]NASA Marshall Space Flight Center (Mail Code: ZP10, Marshall Space Flight Center, AL, 35812, Jim.Spann@nasa.gov)

Introduction: Exploring and ultimately establishing a permanent presence on the surface of Mars will necessitate an understanding the weather conditions and the ability to forecast its dynamic behavior. The meteorology of Mars will need to be developed. This abstract puts forth a concept for a Mars Meteorological Network that will be used to investigate the Mars atmosphere behavior, explore the surface environment, and prepare for operational activities. It is proposed that the long term and the dynamic nature of the lower atmosphere and surface of Mars be observed with a distributed global array of simple automated surface nodes. The data would be ingested into the Mars Global Reference Atmospheric Model (Mars-GRAM) and other research tools for analyses to gain a better understanding of the atmospheric conditions on Mars.

Mars Weather Network: The Mars Weather Network is conceived as a distributed array of small and simple automated nodes located across the surface. The array would be modular to enable the evolution of the array, in number of nodes and layout.

Surface measurements of the lower atmosphere of Mars including the boundary layer would provide information that is unable to be determined through the use of orbiters. The majority of the information about the atmosphere of Mars that has been used to improve Mars-GRAM in recent years has been generated from the use of nadir and limb data from TES onboard Mars Global Surveyor. The addition of detailed, long-term meteorological data from the surface of Mars would fill a void in the overall understanding of the atmosphere of Mars.

Of particular interest on the surface of Mars would be the measurement of temperature, pressure, winds and dust over an extended period of time. This longer duration coverage is necessary to determine the diurnal as well as seasonal variations of the atmosphere of Mars. Ultimately expanding to a network of surface stations would provide a greater understanding of the local, regional, and global atmospheric variations on Mars.

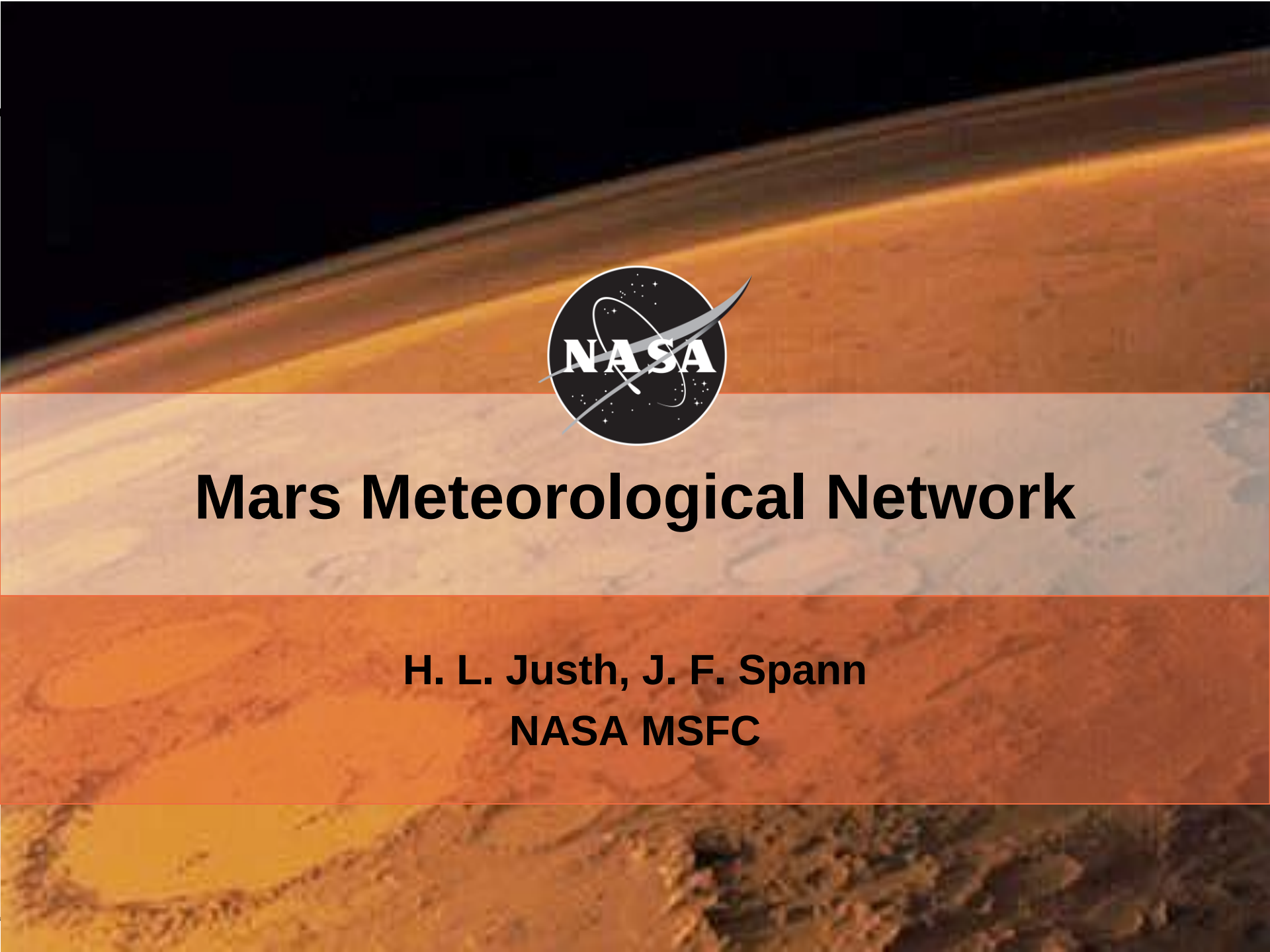
The measurements from a Mars meteorological network could then be used through model-versus-data comparisons to improve existing Mars atmospheric models including Mars-GRAM. As appropriate, Mars atmospheric data could also be used to build auxiliary profiles, which can be utilized as a Mars-GRAM model input option. These improved simulations will be vital when designing and planning systems for aerocapture, aerobraking or landed missions to Mars.

Mars Global Reference Atmospheric Model (Mars-GRAM): Mars-GRAM is an engineering-level atmospheric model widely used for diverse mission applications. Applications include systems design, performance analysis, and operations planning for aerobraking, entry descent and landing, and aerocapture. Mars-GRAM has been utilized during the aerobraking operations of Mars Global Surveyor [1], Mars Odyssey and Mars Reconnaissance Orbiter. Mars-GRAM has also been used in the prediction and validation of Mars Pathfinder hypersonic aerodynamics [2], the aerothermodynamic and entry dynamics studies for Mars Polar Lander [3], the Mars Aerocapture System Study (MASS) as well as the Aerocapture Technology Assessment Group (TAG).

Mars-GRAM's perturbation modeling capability is commonly used, in a Monte-Carlo mode, to perform high fidelity engineering end-to-end simulations for entry, descent, and landing (EDL) [4]. Mars-GRAM 2005 has been validated [5] against Radio Science data, and both nadir and limb data from Thermal Emission Spectrometer (TES) [6].

From the surface to 80 km altitude, Mars-GRAM is based on the NASA Ames Mars General Circulation Model (MGCM) [7, 8]. Above 80 km, Mars-GRAM is based on the University of Michigan Mars Thermospheric General Circulation Model (MTGCM) [9, 10]. Mars-GRAM and MGCM use surface topography from Mars Global Surveyor Mars Orbiting Laser Altimeter (MOLA), with altitudes referenced to the MOLA constant potential surface (areoid).

References: [1] Lyons, D. T. et al. (1999) *JSR*, Vol. 36, No. 3, 307-313. [2] Gnoffo, P. A. et al. (1999) *JSR*, Vol. 36, No. 3, 367-373. [3] Queen, E. M. et al. (1999) *JSR*, Vol. 36, No. 3, 421-428. [4] Striepe S. A. at al. (2002) *AIAA Atmospheric Flight Mechanics Conference and Exhibit*, Abstract # 2002-4412. [5] Justus C. G. et al. (2005) *53rd JANNAF Propulsion Meeting*. [6] Smith M. D. (2004) *Icarus*, 167, 148-165. [7] Haberle, R. M. et al. (1993) *JGR*, 98, 3093-3123. [8] Barnes, J. R. et al. (1993) *JGR*, 98, 3125-3148. [9] Bougher, S. W. et al. (1990) *JGR*, 95, 14,811-14,827. [10] Bougher, S. W. et al. (1999) *JGR*, 104, 16,591-16,611.



Mars Meteorological Network

H. L. Justh, J. F. Spann

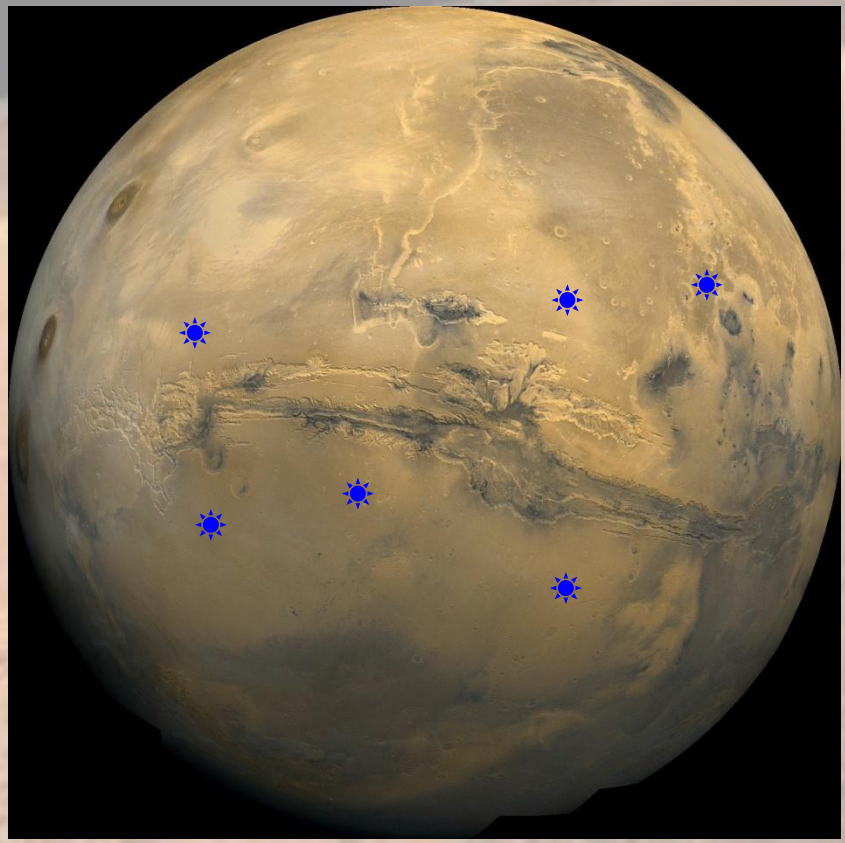
NASA MSFC

Motivation for Mars Meteorological Network

- Detailed, long-term meteorological measurements from the surface of Mars are needed for the understanding of the atmosphere, weather and climate of Mars
- Addresses Mars Exploration Program Analysis Group (MEPAG) Goal IV Objective 1A:
  - Determine the aspects of the atmospheric state that affect aerocapture, EDL and launch from the surface of Mars.
- Address strategic knowledge gaps associated human exploration that the Precursor Science Analysis Group (P-SAG) has determined:
  - GROUP A 2. Atmospheric Modeling. The atmospheric models for Mars have not been well validated due to a lack of sufficient observational data, and thus our confidence in them (for use in mission engineering) is significantly limited.
  - GROUP B 1. Lower Atmosphere. We do not have sufficient Martian atmospheric observations to confidently model winds, which significantly affect EDL design, or atmospheric electricity, in the forms of electric fields and conductivity, to understand the risks to ascent vehicles, ground systems, and human explorers

Mars Meteorological Network Concept

- Evolving grid
- Large scale – global
- Small surface package
  - Released from orbit
  - Autonomous
  - Standard suite
  - In situ and remote sensing
  - Data store and dump
  - Low power
  - Small mass

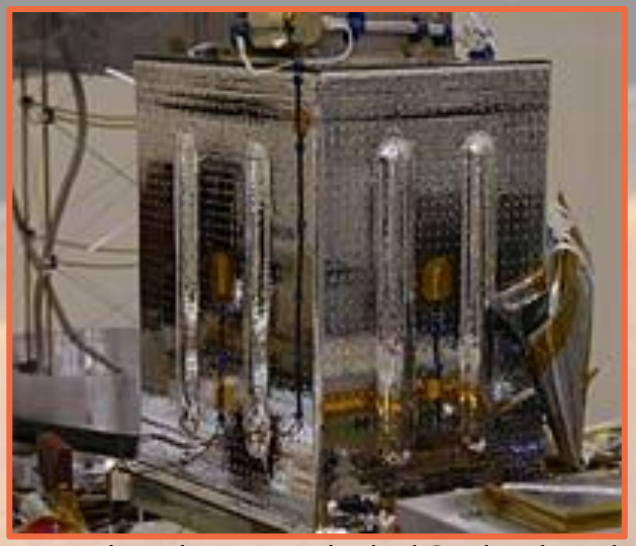


(Image Courtesy of: NASA/JPL/USGS)

Nominal Payload

- Temperature
- Pressure
- Wind vector
- Lidar
- Camera

Instrument	Mass (kg)	Power (W)	Tlm (Mb/sol)
winds/temp /press	0.7	0.1	2
Lidar	4.5	10	0.02
Camera	4.5	20	135



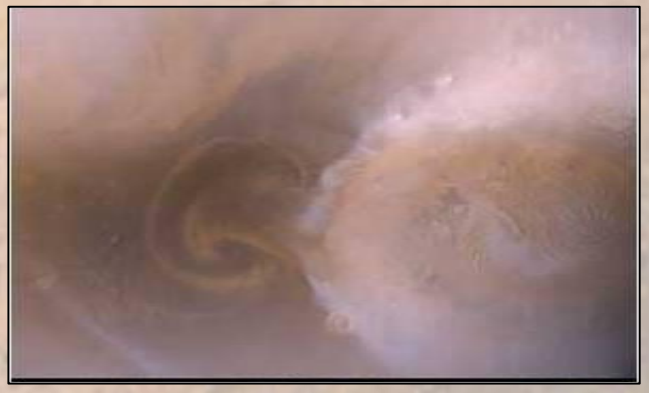
Mars Phoenix Meteorological Station (MET) (Image Courtesy of Canadian Space Agency)

Mars Phoenix Surface Stereo Imager (SSI) (Image Courtesy of Univ. of Arizona)

Data products

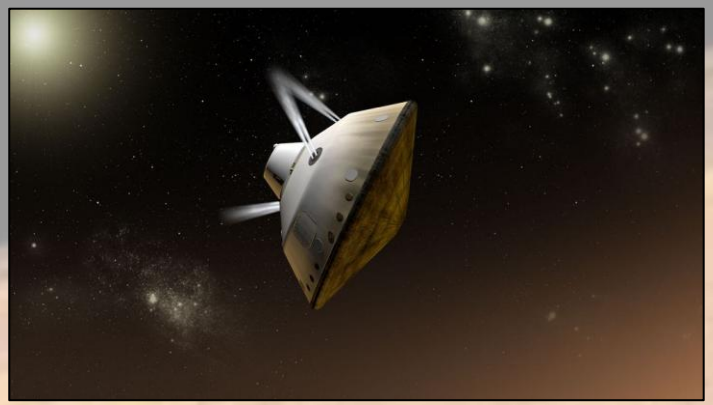
- Of particular interest on the surface of Mars would be the measurement of temperature, pressure, winds and dust over an extended period of time
- Longer duration coverage is necessary to determine the diurnal as well as seasonal variations of the atmosphere of Mars
- Ultimately expanding to a network of surface stations would provide a greater understanding of the local, regional, and global atmospheric variations on Mars

Mars Clouds (Image courtesy of NASA/JPL)



Mars dust storm “kicked up” by drainage flow off of polar cap (Image courtesy of NASA/JPL)

Use of data products



Artist concept showing thrusters firing during the entry, descent and landing phase for NASA's Mars Science Laboratory mission to Mars (Image courtesy of NASA/JPL-Caltech)

- Mars Meteorological Network measurements could then be used through model-versus-data comparisons to improve existing Mars atmospheric models including Mars-GRAM
- As appropriate, Mars Meteorological Network measurements could also be used to build auxiliary profiles, which can be utilized as a Mars-GRAM model input option
- Improved simulations can be used in designing and planning systems for aerocapture, aerobraking or landed missions to Mars
  - Increased precision in determining the orbital adjustments necessary in aerocapture or aerobraking missions
  - Increased accuracy in EDL trajectories resulting in more exact predictions of landing site locations

Mars Climatological Database

- Develop a database of vertical profiles at the Mars Meteorological Network locations
- Data in the profile would include the monthly means and standard deviations for atmospheric parameters
- This would allow the Mars-GRAM user to simulate a trajectory through network locations
- If a given trajectory point is sufficiently close to a network location, the mean data from that site would replace the mean values of the conventional Mars-GRAM climatology, and the standard deviations from this site would replace the conventional Mars-GRAM standard deviations in the perturbation model computations

Mars Global Reference Atmospheric Model (Mars-GRAM)

- Engineering-level atmospheric model widely used for diverse mission applications
- Mars-GRAM's perturbation modeling capability is commonly used, in a Monte-Carlo mode, to perform high fidelity engineering end-to-end simulations for entry, descent, and landing[1]
- Mars-GRAM has been utilized during previous aerobraking operations:
  - Mars Global Surveyor (MGS)
  - Mars Odyssey (ODY)
  - Mars Reconnaissance Orbiter (MRO)
- Mars-GRAM was most recently used to assess Mars Science Laboratory (MSL) landing capabilities
- From the surface to 80 km altitude, Mars-GRAM is based on NASA Ames Mars General Circulation Model (MGCM)[2]
  - Mars-GRAM and MGCM use surface topography from Mars Global Surveyor Mars Orbiter Laser Altimeter (MOLA), with altitudes referenced to the MOLA areoid, or constant potential surface
- Above 80 km, Mars-GRAM is based on the University of Michigan Mars Thermospheric General Circulation Model (MTGCM)[3]

Conclusions

Sunset over Gusev Crater taken by Spirit (Image Courtesy of NASA/JPL/Texas A&M/Cornell)

- The Mars Meteorological Network addresses MEPAG goals and strategic knowledge gaps related to the atmosphere of Mars
  - Provide critical input for aerocapture, entry/descent/landing (EDL) and launch from the surface of Mars.
- A network of surface meteorology stations would provide a greater understanding of the local, regional, and global atmospheric variations on Mars
- Data from the Mars Meteorological Network could be used to improve existing Mars atmospheric models including Mars-GRAM

References

[1]Striepe S. A. at al., *AIAA Atmospheric Flight Mechanics Conference and Exhibit*, Abstract # 2002-4412, 2002.

[2]Haberle, R. M., Pollack, J. B., Barnes, J. R., et al., "Mars Atmospheric Dynamics as Simulated by the NASA Ames General Circulation Model 1. The Zonal-Mean Circulation." *Journal of Geophysical Research*, Vol. 98, No. E2 1993, pp. 3093-3123.

[3]Bougher, S.W., et al., "The Mars Thermosphere: 2. General Circulation with Coupled Dynamics and Composition." *Journal of Geophysical Research*, Vol. 95, No. B9, 1990, pp. 14,811-14,827.