Solicitation: MAVEN Critical Data Products Request for Proposal MFS-269-212010

Date of Submission: 2010 February 28

Proposal Title: Thermospheric variability observed by past aerobraking missions and radio occultation experiments

Short Title: Empirical thermospheric variability

Applicant Organization:
Trustees of Boston University, 881 Commonwealth Avenue, Boston, MA 02215

Type of Proposing Institution: Educational Institution

Submission: By email to michele.f.schneider@jpl.nasa.gov by 2010 March 1, 3pm local time

Business Office Point of Contact:
Ms. Maureen Rodgers
Office of Sponsored Programs
Boston University
25 Buick Street
Boston, MA 02215

Phone: 617/353-4365
Fax: 617/353-6660
Email: mrodgers@bu.edu

Research Provider:
Dr. Paul Withers
Center for Space Physics
Boston University
725 Commonwealth Avenue
Boston MA 02215

Phone: 617/353-1531
Fax: 617/353-6463
Email: withers@bu.edu

Researcher Signature and Date:

Paul Withers
Signature

2010.02.05
Date

Institutional Endorsement:
John F. Imbergamo, Senior Associate Vice President for Financial Affairs
For the Trustees of Boston University

Signature
John F. Imbergamo
Senior Associate VP for
Financial Affairs

02/19/2010
Date

**Goal: To support MAVEN operations (125/150 km periapsis) by providing empirical data products on thermospheric variability from observations by earlier aerobraking missions and radio occultation experiments.**

We propose to use accelerometer data from MAVEN's three predecessors (MGS, ODY and MRO) and MGS radio science (RS) occultation data to investigate how thermospheric conditions vary about their background states. Large-scale physics-based thermospheric models are highly suited to predicting mean states (climate), but are less suited to predicting variability (weather) (Bougher et al., 2006; Angelats i Coll et al., 2004). Safe operation of MAVEN requires consideration of "worst-case weather" as well as expected climate. Our deliverables will reflect conditions (e.g. Ls, latitude, LST, lower atmospheric dust loading, solar forcings) as they existed for those earlier missions. When these are close enough to conditions expected by MAVEN, our deliverables can be directly used in mission planning. When they are not, our deliverables can be used to validate models that predict orbit-to-orbit variability. Since extreme variability may result in mission failure, variability predictions should not rely solely on theoretical models without robust validation of their predictions. Validation requires real data.

From earlier aerobraking missions, we shall use archived fitted densities ($\rho_{fit}$) and density scale heights ($H_{fit}$) at 10 km vertical intervals (Withers et al., 2003). Temperatures are proportional to $H_{fit}$ and pressures, $p_{fit}$, can be approximated as $\rho_{fit}$ g $H_{fit}$. The typical vertical range is 100-160 km. The ionospheric peak seen in RS electron density profiles occurs at a predictable pressure level of ~1 nbar x cos(solar zenith angle) and an altitude of $z_{RSpk}$ (130-140 km for typical MGS occultations). The neutral scale height, $H_{RSpk}$, can be found from the width of the peak (Withers, 2009). If $z_{RSpk}$ differs from some average or pre-disturbance value by $\Delta z$, then the difference in pressure at this location, $\Delta p_{RS}$, is p $\Delta z/H_{RSpk}$, where p is ~1 nbar x cos(solar zenith angle). Thus variations in $z_{RSpk}$ can be used to characterize pressure variations. Uncertainty in $\rho_{fit}$ is <5% at 125 km, increasing to ~30% at 150 km. Uncertainty in $H_{fit}$ is ~1 km at both altitudes. Uncertainties in $z_{RSpk}$ and $H_{RSpk}$ are ~2 km. Our derived deliverables will also include uncertainties, although space limitations prevent a task-by-task description of how they are derived from the input data and their uncertainties. Measurement uncertainties are smaller than atmospheric variability over many spatial and temporal scales. Tasks 1 and 2 are relatively mechanical and will be performed for all available conditions. Tasks 3 and 4 are more complex and will be targeted towards MAVEN "deep-dip" conditions as much as possible. Each task's deliverables are specified in the schedule of deliverables.

## Task 1: Intrinsic variability

($\rho_{fit}$, $H_{fit}$, $p_{fit}$, $z_{RSpk}$, $H_{RSpk}$, $\Delta p_{RS}$ will be used)

When one martian sol is an integer multiple of the orbital period of an aerobraking spacecraft (e.g. period is 1/4 sol), the spacecraft repeatedly passes through the same Ls, latitude, longitude, LST, and altitude in the atmosphere. For reasonable definitions of "the same", five or so passes occur at the same longitude as the spacecraft orbit moves through this resonance condition. Fig.1 shows density variations seen by MGS. RS profiles, typically recorded every 2 hours, also often sample the same conditions repeatedly over several sols. For instance, there are 6 RS profiles from Mars Year (MY) 27, Ls=218$^{o}$-222$^{o}$, 64-66$^{o}$N, 160-180$^{o}$E, LST=14.6-14.7 hrs,. We call such groups of data points "clusters". The measured variability in these situations is the most direct indication of thermospheric variations. We shall characterize this variability.

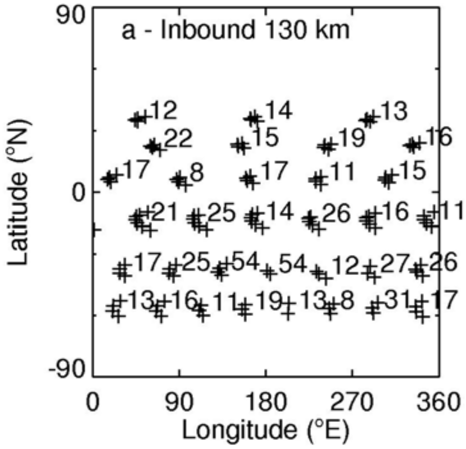

Fig 1. Standard deviation of inbound dayside density measurements at 130 km from Phase 2 of MGS aerobraking as percentage of mean density. Clusters show 3:1 to 8:1 orbital resonances. From Withers et al. (2003).

<u>Task 2: Variations with longitude</u>
($\rho_{fit}$, $H_{fit}$, $p_{fit}$, $z_{RSpk}$, $H_{RSpk}$, $\Delta p_{RS}$ will be used)

MGS aerobraking found that thermal tides cause large variations in atmospheric density with longitude (Fig. 2) (Keating et al., 1998; Withers et al., 2003). They also cause $z_{RSpk}$ to vary (Bougher et al., 2001). Since zonal density variations are strong (~50%) at 120 km, but weak (<10%) at 150 km, scale heights must also vary with longitude. We shall characterize by how much atmospheric properties vary with longitude at fixed Ls, latitude, LST and altitude (fixed pressure level for $z_{RSpk}$, $H_{RSpk}$). Simple metrics, such as standard deviations, will be used, rather than harmonic fits, as they are most suited to engineering needs.

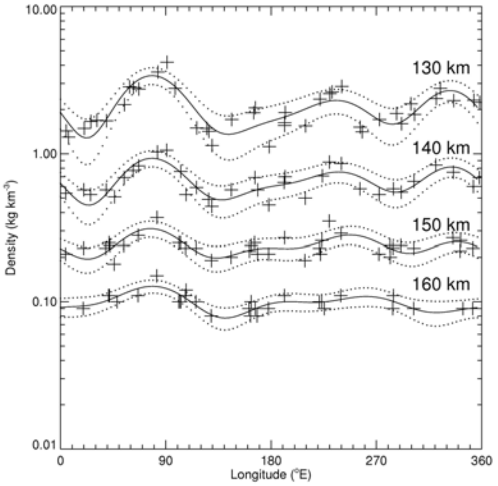

Fig. 2. Dayside densities at 130, 140, 150 and 160 km between 10°N and 20°N from Phase 2 of MGS aerobraking. From Withers et al. (2003).

<u>Task 3: Response to extreme solar events</u>
($\rho_{fit}$, $H_{fit}$, $p_{fit}$ will be used)

Solar flares and coronal mass ejections (CMEs) are known to affect the martian ionosphere (Mendillo et al., 2006; Morgan et al., 2006). Thermospheric densities also respond to short-term changes in solar irradiance, as shown around orbit 90 of MGS aerobraking in Fig. 2 of Keating et al. (1998) and here in Fig. 3. Possible neutral responses to CMEs have not been studied greatly. We will identify instances where solar flares, short-term increases in solar irradiance due to (e.g.) solar rotation, and CMEs occurred during aerobraking periods, then investigate how $\rho_{fit}$, $H_{fit}$, and $p_{fit}$ measured around these times changed from their pre-disturbance values (allowing for CME travel time from the Sun as necessary). We will not use RS data in this task unless directed to do so, because no previous work has shown that $z_{RSpk}$ and $H_{RSpk}$ respond strongly to solar disturbances. We will not address CIRs since they are hard to identify at Mars.

Known flares and CMEs will be identified from terrestrial data. Clearly, this will include some disturbances that affected Earth, but not Mars, as well as exclude some disturbances that affected Mars, but were not visible from Earth. We will consider this when interpreting our results. Also, CMEs will be identified from MGS ER background counts (Morgan et al., 2006). We have ongoing collaborations with several ER team members who are also on the MAVEN team, so data access will be straight-forward. Inspection of two test periods shows that some extreme solar events did occur during earlier aerobraking missions. According to http://hea-www.harvard.edu/trace/flare_catalog/ and http://cdaw.gsfc.nasa.gov/CME_list/, 5 X-class flares and 7 halo (Earth-directed) CMEs occurred in November 1998 (MGS Phase 2) and 5 X-class flares and 22 halo CMEs occurred in October-December 2001 (ODY). We shall focus on large events because their potential impact is greatest.

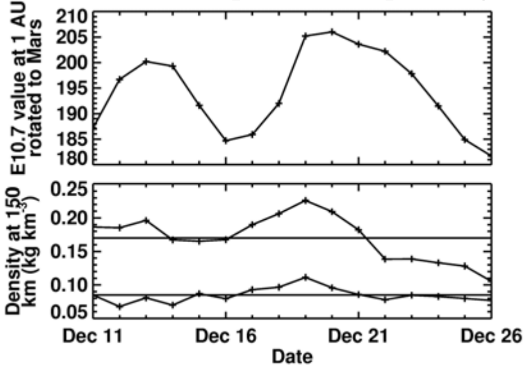

Fig. 3. Top: E10.7, a solar flux proxy, at 1 AU rotated from the heliocentric longitude of Earth to Mars. Bottom: 3-day average of inbound (0.1

kg km$^{-3}$) and outbound (0.2) densities measured at 150 km by ODY in 2006. High densities on 19 Dec correlate with high solar flux.

### Task 4: Response to dust storms

($\rho_{fit}$, $H_{fit}$, $p_{fit}$, $z_{RSpk}$, $H_{RSpk}$, $\Delta p_{RS}$ will be used)

There are two instances where aerobraking data are affected by dust storms. First, the Noachis dust storm seen by TES in November 1997 (MGS orbit 50, periapsis at 40$^{o}$N) that affected aerobraking operations (Keating et al., 1998). The atmospheric response is shown in Fig. 4. Second, the TES-observed global dust storm of summer/fall 2006 that waned as ODY aerobraking commenced (periapsis at 70$^{o}$N) (Smith, 2008). MGS RS data from Ls=90$^{o}$-215$^{o}$, 60-70$^{o}$N overlap in time with a TES-observed dust storm that commenced at Ls=200$^{o}$ of MY 26 and had moderate dust opacity poleward of 30$^{o}$S, but smaller opacities north of 30$^{o}$S (Smith, 2008). Similarly, MGS RS data from Ls=120$^{o}$-225$^{o}$, 60-70$^{o}$N overlap in time with a THEMIS-observed dust storm that commenced at Ls=200$^{o}$ of MY 27 and was concentrated in the tropics (Smith, 2009). Moderate to large dust storms are included in these four examples. TES/THEMIS dust opacities are readily available from Mike Smith, GSFC, with whom we regularly collaborate. We shall investigate how thermospheric properties at a range of altitudes varied with global/local dust opacities and distance from dusty regions.

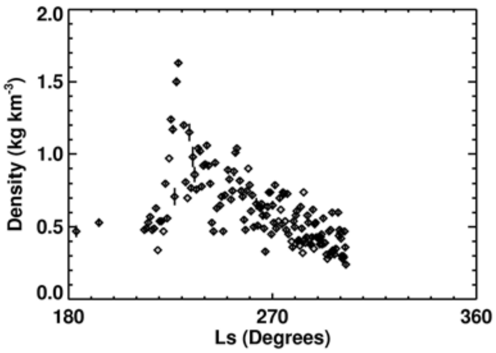

Fig. 4. Outbound densities at 150 km from Phase 1 of MGS aerobraking. Dust storm effects are centred on Ls=220$^{o}$. Uncertainties (vertical lines) are small.

### PDS Delivery Plan

These tasks will generate a set of ASCII tables that will be delivered to the PDS Atmospheres Node for review and archiving. Label files, index files, associated documentation, and so on will also be delivered. We have archived two accelerometer-derived datasets at the Atmospheres Node (MERIMU_1001, MER entry profiles, and ODYA_1001, ODY aerobraking densities and scale heights) and are in the process of archiving the PHX entry profiles. The deliverables from this project will be prepared, formatted, delivered, and revised using our established tools and pipelines. Copies will also be sent to JPL and MAVEN.

### Personnel

PI Withers has extensive experience working with accelerometer and radio science observations of Mars (Withers et al, 2003; Mendillo et al., 2006; Withers, 2009). The software tools he has developed for working with these datasets will be used in this project. Staff Researcher Clara Narvaez earned a BA in Astronomy in 2007. She has worked in the same group as PI Withers since 2007, working on data processing/analysis projects involving the terrestrial atmosphere. She has regularly presented her work at scientific meetings and contributed to published papers (Mendillo and Narvaez, 2009, 2010). PI Withers will supervise Narvaez, who will perform the bulk of this work. Both will participate in required telecons. PI Withers will write required reports.

### References

- Angelats i Coll et al. (2004) JGR, 109, doi:10.1029/2003JE002163
- Bougher et al. (2001) GRL, 28, 3091-3094
- Bougher et al. (2006) GRL, 33, doi:10.1029/2005GL024059
- Keating et al. (1998) Science, 279, 1672-1676
- Mendillo et al. (2006) Science, 311, 1135-1138
- Mendillo and Narvaez (2009) Annales Geophysicae, 27, 1679-1694
- Mendillo and Narvaez (2010) Ann. Geo, in press
- Morgan et al. (2006) GRL, 33, doi:10.1029/2006GL026637
- Smith (2008) Ann. Rev. EPS, 36, 191-219
- Smith (2009) Icarus, 202, 444-452
- Withers et al. (2003) Icarus, 164, 14-32
- Withers (2009) Adv. Sp. Res., 44, 277-307

## Schedule of Work and Schedule of Deliverables

A two year effort is proposed with a nominal start date of 1 May 2010. Due dates for deliverables are expressed as months from actual start date. Each Task is divided into several Steps. Strawman levels of effort for PI Withers and Narvaez are assigned to each Step. This level of detail is provided to demonstrate that we have planned how to accomplish each Task in a timely manner, that the requested levels of effort are appropriate, and that the effort is distributed between Withers and Narvaez. The actual level of effort assigned to each Task may be adjusted as circumstances dictate.

| | |
|---|---|
| Effort of PI Withers | 0.1 FTE (1.2 months) per year for two years |
| Effort of Staff Researcher Narvaez | 0.9 FTE (10.8 months) per year for two years |

We would be willing to enter into negotiations concerning a **descoped effort** if NASA deems only some tasks worthwhile. This schedule of work can be used to infer the likely cost of a descoped effort.

### Ongoing activities (Months 1-24, 0.8 m Withers)

Step 0.1 - Day-to-day supervision of Narvaez by Withers. (0.1 m Withers every 6 months)

Step 0.2 - Preparation for telecons, reviews, and reports. (0.1 m Withers every 6 months)

### Preparatory activities not associated with any specific Task (Months 1-2, 0.2 m Withers, 1 m Narvaez)

Step 0.3 - Withers is debriefed by MAVEN project on how MAVEN project wishes to modify proposed tasks and work plan in order to optimize value of results to MAVEN.

Step 0.4 - Withers teaches Narvaez how to manipulate existing aerobraking ($\rho_{fit}$, $H_{fit}$) and RS ($z_{RSpk}$, $H_{RSpk}$, $\Delta p_{RS}$) datasets. (0.1 m Withers, 0.5 m Narvaez)

Step 0.5 - Withers trains Narvaez in assembling PDS-compliant datasets and documentation. (0.1 m Withers, 0.5 m Narvaez)

Task 1 (Months 3-8, 0.3 m Withers, 5.9 m Narvaez)

Step 1.1 - Definition of ranges of Ls, latitude, longitude, and LST that should be considered as “the same” for purposes of measuring intrinsic variability. Experimentation and sensitivity testing required to ensure ranges are not so small that few data points are included, but not so large that phenomena other than day-to-day variability at one location affect results. Also important is whether the same ranges are used for aerobraking and RS work. (0.1 m Withers, 1 m Narvaez)

Step 1.2 - Derivation of data products and uncertainties from aerobraking datasets. (0.1 m Withers, 1.4 m Narvaez)

Step 1.3 - Derivation of data products and uncertainties from RS datasets. Unlike the aerobraking datasets, where clusters of data points occur in a predictable way during orbit resonances, suitable clusters of RS data points may occur throughout the entire dataset. (1.5 m Narvaez)

Step 1.4 - Organization of aerobraking and RS data products into planned tables. (0.5 m Narvaez)

Step 1.5 - Production of additional documentation required for PDS archiving and response to PDS liens. (0.5 m Narvaez)

Step 1.6 - Production of summary/synthesis of the results. Format and content to be defined after inspection of the results. (0.1 m Withers, 1 m Narvaez)

**Deliverable 1 - Set of ASCII tables reporting intrinsic thermospheric variability and associated documentation. To be delivered by email/ftp to designated MAVEN project contact and PDS. Due at end of Month 8 (December 2010).**

For the aerobraking datasets, there will be one file for each set of clusters of measurements. Each such file will contain a header that provides spacecraft name, Mars Year, Ls, date, F10.7, latitude, altitude, LST, F10.7, and in/outbound direction. Each such file will contain N groups of lines (where N corresponds to the orbital resonance, e.g. 5 groups for the 5:1 resonance). Each group of lines will contain 4 lines. The first line in each group will report the longitude of the cluster and the number of measurements therein. The second line in each group will report the mean value of $\rho_{fit}$ in this cluster and its uncertainty, the standard deviation of $\rho_{fit}$ in this cluster and its uncertainty, the largest value of $\rho_{fit}$ in this cluster and its uncertainty, and the smallest value of $\rho_{fit}$ in this cluster and its uncertainty. The third line in each group will be like the second, but for $H_{fit}$ and the fourth line in each group will be like the second, but for $p_{fit}$.

For the RS datasets, there will be one file for each cluster of measurements. Unlike the aerobraking datasets, clusters will not necessarily occur in sets at a particular latitude. Each file will contain a header that provides Mars Year, Ls, date, F10.7, latitude, altitude, LST, and longitude. The next line will report the same values as the $\rho_{fit}$ line in the aerobraking files, but for $z_{RSpk}$. The following line will do the same, but for $H_{RSpk}$, and the next line will do the same, but for $\Delta p_{RS}/p$.

Task 2 (Months 9-12, 0.3 m Withers, 3.9 m Narvaez)

Step 2.1 - Identification of 10 degree Ls, 10 degree latitude, and 1 hour LST ranges when many aerobraking measurements were made across all longitudes in one Mars Year. (0.5 m Narvaez)

Step 2.2 - Same as Step 2.1, but for RS measurements. (0.5 m Narvaez)

Step 2.3 - Derivation of data products and uncertainties from aerobraking datasets. (0.1 m Withers, 1 m Narvaez)

Step 2.4 - Same as Step 2.2, but for RS measurements. (0.1 m Withers, 1 m Narvaez)

Step 2.5 - Production of additional documentation required for PDS archiving and response to PDS liens. (0.5 m Narvaez)

Step 2.6 - Production of summary/synthesis of the results. Format and content to be defined after inspection of the results. (0.1 m Withers, 0.4 m Narvaez)

**Deliverable 2 - Set of ASCII tables reporting thermospheric variability with longitude and associated documentation. To be delivered by email/ftp to designated MAVEN project contact and PDS. Due at end of Month 12 (April 2011).**

The aerobraking results will be reported in 7 files with many groups of lines, where each file is distinguished by a single altitude (e.g., 100 km, 110 km, ..., 160 km). The first line in each group will report spacecraft name, Mars Year, Ls, date, F10.7, latitude, LST, and number of data points. The second line in each group will report the corresponding standard deviation of $\rho_{\mathrm{fit}}$ and its uncertainty (as percentages of the zonal mean), the 10th percentile value of $\rho_{\mathrm{fit}}$ and its uncertainty, the 90th percentile value of $\rho_{\mathrm{fit}}$ and its uncertainty, the smallest value of of $\rho_{\mathrm{fit}}$ and its uncertainty, and the largest value of $\rho_{\mathrm{fit}}$ and its uncertainty. The third line in each group will be like the second, but for $H_{\mathrm{fit}}$, and the fourth line in each group will be like the second, but for $p_{\mathrm{fit}}$.

The RS results will be reported in one file with many groups of lines. The first line in each group will report Mars Year, Ls, date, F10.7, latitude, LST, and number of data points. The next line will report the same values as the $\rho_{\mathrm{fit}}$ line in the aerobraking files, but for $z_{\mathrm{RSpk}}$. The following line will do the same, but for $H_{\mathrm{RSpk}}$, and the next line will do the same, but for $\Delta p_{\mathrm{RS}}/p$.

Task 3 (Months 13-18, 0.4 m Withers, 5.4 m Narvaez)

Step 3.1 - Use of Earth-based data to identify instances when solar flares, large short-term increases in solar irradiance due to solar rotation, and large CMEs occurred that could have affected Mars during aerobraking operations. Determination of suitable metrics for characterizing the strengths of these solar disturbances. (0.2 m Withers, 1 m Narvaez)

Step 3.2 - Acquisition of MGS ER data, followed by use of MGS ER data to identify large CMEs at Mars during aerobraking operations. Determination of suitable metrics for characterizing the strengths of these solar disturbances. (1 m Narvaez)

Step 3.3 - Derivation of data products and uncertainties from aerobraking datasets. (0.1 m Withers, 1.5 m Narvaez)

Step 3.4 - Production of additional documentation required for PDS archiving and response to PDS liens. (1 m Narvaez)

Step 3.5 - Production of summary/synthesis of the results. Format and content to be defined after inspection of the results. (0.1 m Withers, 0.9 m Narvaez)

**Deliverable 3 - Set of ASCII tables reporting thermospheric response to extreme solar events and associated documentation. To be delivered by email/ftp to designated MAVEN project contact and PDS. Due at end of Month 18 (October 2011).**

These results will be reported in 12 (4 x 3) files, one for each type of solar disturbance (solar flares, solar rotation, CMEs found in Earth-based data, CMEs found in MGS ER data) and data type ($\rho_{\mathrm{fit}}$, $H_{\mathrm{fit}}$, $p_{\mathrm{fit}}$). Each file will contain many groups of lines. The first line in each group will report spacecraft name, Mars Year, Ls, date, and a description of the solar event. The next line in the group will report altitude (e.g. 100 km), latitude, LST, difference between (e.g.) $\rho_{\mathrm{fit}}$ before and after the solar event relative to pre-event value, standard deviation of one week of $\rho_{\mathrm{fit}}$ measurements prior to solar event (so that the significance of solar-induced changes can be evaluated), and typical uncertainty in $\rho_{\mathrm{fit}}$ during this period. Subsequent lines in the group will report results for other altitudes (100, 110, ..., 160 km)

Task 4 (Months 19-24, 0.4 m Withers, 5.4 m Narvaez)

Step 4.1 - Acquisition of TES and THEMIS dust opacity data. Ingestion into computer programs. (0.1 m Withers, 0.5 m Narvaez)

Step 4.2 - Identification of dust storms during periods of aerobraking or RS measurements. Characterization of spatial distribution of dust during these storms and its evolution with time. (0.1 m Withers, 1 m Narvaez)

Step 4.3 - Derivation of data products and uncertainties from aerobraking datasets. (1 m Narvaez)

Step 4.4 - Same as Step 4.3, but for RS measurements. (1 m Narvaez)

Step 4.5 - Since individual dust storms differ widely, simple tables of data will have limited value without a supporting discussion of general trends and features. The contents of this discussion are more directly useful for influencing MAVEN planning. Therefore, investigate how properties of thermospheric response (e.g. altitudes affected, magnitude of response, delay time between dust storm onset and response, duration of response) depend on dust storm properties, then synthesize findings into a report. (0.2 m Withers, 1.5 m Narvaez)

Step 4.6 - Production of additional documentation required for PDS archiving and response to PDS liens. (0.4 m Narvaez)

**Deliverable 4 - Set of ASCII tables reporting thermospheric response to dust storms and associated documentation, plus report synthesizing findings. To be delivered by email/ftp to designated MAVEN project contact and PDS. Due at end of Month 24 (April 2012).**

One file containing many groups of lines will be produced for each dust storm whose effects are detectable in thermospheric datasets. For the aerobraking datasets, each group of lines will correspond to one orbit. The first line will report spacecraft name, Mars Year, Ls, date, F10.7, orbit number, and relevant regional/global-scale dust characteristics. The second line will report altitude (e.g. 100 km), latitude, longitude, LST, in/outbound direction, relevant local-scale dust characteristics, $\rho_{fit}$ and uncertainty, $H_{fit}$ and uncertainty, and $p_{fit}$ and uncertainty. Subsequent lines in the group will report results for other altitudes and in/outbound directions. For the RS datasets, each group of lines will correspond to one occultation and each group will contain only one line. This line will report Mars Year, Ls, date, F10.7, latitude, longitude, LST, relevant local/regional/global-scale dust characteristics, $z_{RSpk}$ and uncertainty, $H_{RSpk}$ and uncertainty, and $\Delta p_{RS}/p$ and uncertainty.

The length and specific content of the synthesis report will be determined later.

| Reporting Deliverables | Due at end of Month # |
|---|---|
| R1 - Kickoff telecon with MAVEN project | 1 |
| R2 - Monthly telecons with MAVEN project | 1, 2, ..., 24 |
| R3 - Semi-annual telecon reviews with MAVEN project scientist | 6, 12, 18, 24 |
| R4 - Annual report to MAVEN project and Mars Program | 12 |
| R5 - Final report to MAVEN project and Mars Program | 24 |

Budget Narrative

| | |
|---|---|
| **Effort of PI Withers** | **0.1 FTE (1.2 months) per year for two years** |
| **Effort of Staff Researcher Narvaez** | **0.9 FTE (10.8 months) per year for two years** |

Narvaez's effort is kept below 1.0 FTE to ensure completion of wrap-up work on ongoing projects.

Domestic Travel
1 person-trip (Narvaez) in Year 1 to 5-day scientific conference (e.g. Fall AGU)
1 person-trip (Withers) in Year 1 to 2-day MAVEN team meeting
1 person-trip (Narvaez) in Year 2 to 2-day MAVEN team meeting

Domestic scientific conference
Justification: Train Narvaez to present results at scientific meetings, exchange ideas with wide spectrum of colleagues, receive feedback from colleagues.

MAVEN team meetings
Justification: Have in-depth discussions with broad range of MAVEN scientists and engineers to ensure activities are responsive to project needs. Attending MAVEN team meetings is a valuable supplement to telecons with the MAVEN project scientist and a small subset of other MAVEN personnel. Face-to-face discussions will also enhance the productivity of subsequent telecons.

Foreign Travel
1 person-trip (Narvaez) in Year 2 to 5-day scientific conference (e.g. EGU)

Foreign scientific conference
Justification: Same as domestic scientific conference, but motivated by the joint NASA/ESA 2016 Trace Gas Orbiter. This mission will be ESA's first planetary aerobraking experience. We plan to share our results with European scientists, project managers, and engineers, as well as to learn from their planning activities.

One publication is planned based on reports and summaries generated throughout the duration of this proposed work. Publication costs, based on JGR page charges, are $500 in Year 2 only.
Software (IDL licence for Narvaez) and departmental tax on research funding to support network services - $500 per year.
Supplies (long distance telephone, fax, delivery services) - $500 per year.