Goal: Use MER entry profiles and TES data to support efforts to predict atmospheric conditions during MSL EDL.

What orbital observations can provide ρ(z) profiles for the MSL EDL latitude (45S-45N), local time (14:00-17:30) and season (Ls = 120^o-150^o) (Constraints, 2007; Overview, 2007)?

Occultations (e.g. SPICAM, radio science) cannot cover the entire latitude and seasonal range. There are only 305 MGS RS profiles available for this 90^o latitude and 30^o Ls range (MGS RS, 2007). The MRO MCS experiment will not acquire data at Ls=120^o-150^o until Fall 2008. MGS TES has measured T(p) profiles at all latitudes, all seasons, and 14:00 hrs for multiple Mars years (Smith, 2004). Therefore TES will be the prime dataset constraining atmospheric predictions for MSL EDL for the next 18 months.

TES measures infra-red radiances, then derives T(p) with vertical resolution ~10 km – but without an absolute altitude reference. MSL needs ρ(z) with km-scale vertical resolution (RFP, 2007; Golombek et al., 2003). ρ(z) and T(z) profiles, with uncertainties, can be derived from TES T(p) profiles using hydrostatic equilibrium and a boundary condition, but are not a common data product. The broad, overlapping TES weighting functions and potentially correlated, non-Gaussian errors in T and p introduce complexity here. TES T(p) profiles have been validated against many observations and models (Smith, 2004), but TES-derived ρ(z) and T(z) profiles must be validated further.

Withers was a member of MER's EDL Atmospheric Advisory Group. We have published MER ρ(z), p(z), and T(z) profiles (~10S, Ls ~ 330^o, 14:00 hrs, Δz < 1 km, z~5–80 km) (Withers and Smith, 2006). Comparisons between TES-derived ρ(z) and T(z) profiles and MER ρ(z) and T(z) profiles can validate the TES data products. TES T(p) profiles were obtained at times and locations near those of MER EDL.

After validating TES-derived ρ(z) profiles at Ls=330^o (MER), we shall obtain TES-derived ρ(z) profiles from MSL landing sites at Ls=120^o-150^o. Both MER sites are within the possible MSL landing region, are safe for EDL, and are scientifically interesting. The MER/MSL EDL local times are similar.

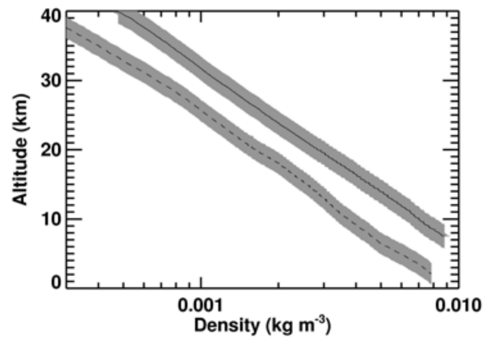

Fig 1. Density profiles for Spirit (solid line) and Opportunity (dashed line, offset by 5km) with 1σ errors (Withers and Smith, 2006).

Uncertainties in MER ρ and z are ~5% and ~1.5 km. There are several contributions to uncertainties in TES-derived ρ(z), including the assumed surface pressure, uncertainties in T (~4K or 2%), and the poor vertical resolution of the T(p) profiles (Withers and Smith, 2006). 4K uncertainties apply to TES temperature profiles with 10 km vertical resolution; uncertainties in the temperature at a specified altitude within that 10 km range are larger. Since dT/dz ~ -1.5 K/km, the TES temperature uncertainty at a specified altitude within the 10 km range is more like 15 K. Preliminary work suggests that uncertainties in TES-derived ρ(z) are ~10%.

Orbital observations cannot fill the MSL EDL parameter space (45S-45N, 14:00-17:30 hrs, Ls = 120^o-150^o). Models will be necessary to extrapolate orbital observations into unobserved regions of parameter space. Models also predict unobserved variables (e.g. winds).

Engineers designing MSL EDL are likely to use models (e.g. MarsGRAM) to supplement a suitable compilation of observations. Therefore the MSL Project needs to know (1) which of the available models (e.g. Ames MGCM, MRAMS, and many others) are best and (2) how uncertain their predicted $\rho(z)$ profiles are.

A model is not necessarily good for MSL EDL support just because it reproduces TES T(p) observations well; it must be shown to reproduce $\rho(z)$ profiles as well. A model with errors in surface pressure or in vertical structure on scales less than the 10 km TES resolution could reproduce TES T(p), but not $\rho(z)$ profiles. Comparison of observed and predicted MER EDL $\rho(z)$ profiles will test the models likely to support MSL EDL and quantify their uncertainties.

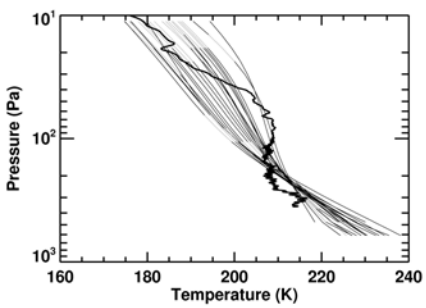

Fig 2. Spirit and TES T(p) profiles

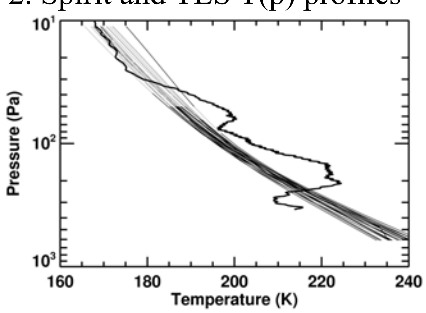

Fig 3. Opportunity and TES T(p) profiles

Having established that MER $\rho(z)$ profiles are valuable to MSL EDL planning, we now outline the objectives of this effort. Timelines and deliverables appear in the Schedule.

<u>Objective 1:</u> Characterize how TES-derived $\rho(z)$ and T(z) differ from MER EDL $\rho(z)$ and T(z) measurements
<u>Description:</u> Attend site selection meeting; meet with scientists using TES T(p) profiles to determine $\rho(z)$, T(z), vertical resolutions, and uncertainties; determine $\rho(z)$, T(z), vertical resolutions, and uncertainties for MER EDL from TES T(p) profiles; quantify how TES-derived $\rho(z)$ and T(z) differ from in situ $\rho(z)$ and T(z) measurements.

<u>Objective 2:</u> Derive representative $\rho(z)$ and T(z) profiles from TES T(p) profiles for candidate landing sites
<u>Description:</u> Identify TES T(p) profiles consistent with candidate latitude, LST, and Ls; select subset of profiles; use results of Obj. 1 to derive $\rho(z)$ and T(z) profiles with vertical resolutions and uncertainties.

<u>Objective 3:</u> Compare model $\rho(z)$ predictions to MER EDL $\rho(z)$ measurements
<u>Description:</u> Attend site selection meeting; meet with scientists using models to predict $\rho(z)$; acquire existing predictions of $\rho(z)$ for MER EDL; compare to observations.

<u>Objective 4:</u> Archive MER EDL profiles
<u>Description:</u> Generate PDS documentation; convert data products into PDS-compliant formats; deliver them to PDS; PDS review process (MEP, 2007; PDS, 2007).

This project will be led by PI Paul Withers, supported by a Boston University graduate student. An existing collaboration between Withers and Mike Smith will continue. Collaborator Smith will provide advice on TES

Dust: A regional dust storm near Opportunity's landing site peaked in December 2003 and waned during the MER EDLs in January 2004. The MER entry profiles that will be disseminated through this effort can be combined with TES dust observations and studied by other workers to investigate how dust abundance affects $\rho(z)$ profiles in equatorial regions.

T(p) data, including its vertical resolution, uncertainties, and coverage. Smith will advise Withers and Student on the vertical resolution and uncertainties related to the conversion of T(p) into ρ(z) profiles for Obj. 1 and 2. The overlapping TES weighting functions and correlated, non-Gaussian errors introduce complexity here. It is probable that other scientists involved in the MSL EDL planning will also be doing this and collaborations with them will be established during MSL site selection meetings. Many atmospheric predictions for MER EDL have been published (Golombek et al., 2003). Collaborations with the theorists who produced these simulations will be established during MSL site selection meetings in support of Objective 3. Standard PDS procedures and the MEP Data Management Plan will be followed in Objective 4 (MEP, 2007; PDS, 2007).

This team is appropriate for this proposed effort because of Withers's previous work on the MER EDL data (Withers and Smith, 2006). The data products to be used in this effort, MER ρ(z) profiles, are not available from the PDS, so this effort cannot be funded by (e.g.) MDAP. Also, a proposal submitted today to MDAP would not receive notice of selection until approximately July 2008, with funds following months later. This is not suitable for MSL's time-critical needs.

Responsiveness to the Requirements: This effort will quantify the uncertainties and vertical resolutions in TES-derived ρ(z) and T(z) profiles, obtain representative ρ(z) and T(z), with uncertainties, from TES data for candidate MSL EDL sites, and validate models used to support MSL EDL. It will not produce ρ(z) and T(z) from every TES T(p) profile within 45S-45N, 14:00-17:30, Ls=120^{o}-150^{o}, nor produce ρ(z) and T(z) from every TES T(p) profiles at a candidate landing site's latitude, LST, and Ls. Instead, our focus is on determining the uncertainties and vertical resolutions in ρ(z) and T(z). We anticipate that other groups are better suited to the bulk processing of large quantities of data. This effort will partially complete the RFP's task "ρ/T profiles for MSL EDL".

PI Withers will devote 4 months per year to this effort, Student will devote 6 months per year to this effort. Smith's unfunded effort will be ~1 week per year. Withers and Student will work together to achieve each Objective, with effort distributed as shown in the Schedule.

Although Withers has been active in the Mars Program, he has never been a mission Co-Investigator, PI on a grant, or PDS data supplier. Funding this proposal will help Withers become an independently funded researcher whose participation in NASA's Mars Exploration Program is not dependent on other people's grants. A graduate student who is not yet involved in the Mars Exploration Program will play a major role in this effort. Travels funds are requested to ensure that both the student and Withers strengthen their ties to the Mars Exploration Program by attending site selection meetings and conferences.

References:

- Constraints (2007) MSL Engineering Constraints presentation from marsoweb.nas.nasa.gov
- Golombek et al. (2003) J. Geophys. Res., 108, 8072, doi:10.1029/2003JE002074
- MEP (2007) Mars Exploration Program Data Management Plan, http://pds-geosciences.wustl.edu/missions/mep/index.htm
- MGS RS (2007) http://nova.stanford.edu/projects/mgs/
- Overview (2007) MSL Mission Overview presentation from marsoweb.nas.nasa.gov
- PDS (2007) http://pds.jpl.nasa.gov/documents/
- RFP (2007) CDP-RFP-RF180507
- Smith (2004) Icarus, 167, 148-165
- Withers and Smith (2006) Icarus,185,133-142

Schedule of Work and Schedule of Deliverables

A three year (36 month) effort is proposed with a nominal start date of 1 September 2007. Due dates for deliverables are expressed as months from actual start date. Each Objective is divided into several Steps. Level of effort for Withers and Student is assigned to each Step in 0.5 m units. This level of detail is provided to demonstrate that we have planned how to accomplish each Objective in a timely manner, that the requested levels of effort are appropriate, and that the effort is distributed between Withers and Student. The actual level of effort assigned to each Objective may be adjusted as circumstances dictate. Smith's effort will be concentrated on Objectives 1 and 2.

Anticipated landing site selection meeting dates are October 2007 (Month 2), August 2008 (Month 12), and June 2009 (Month 22).

Objective 1: Characterize how TES-derived ρ(z) and T(z) differ from MER EDL ρ(z) and T(z) measurements (Months 1 - 15)

Step 1.1 - Attend site selection meeting and meet with scientists using TES T(p) profiles to determine ρ(z) and T(z) (0.5 m Withers, 0.5 m Student in Months 1-3)

Step 1.2 - Followup discussions with those scientists and Mike Smith about how best to determine ρ(z) and T(z) from TES T(p) profiles, paying attention to vertical resolution and uncertainties; develop and test algorithms (1 m Withers, 1.5 m Student in Months 4-6)

Step 1.3 - Determine ρ(z), T(z), and uncertainties for Spirit and Opportunity EDL from TES T(p) profiles (1 m Withers, 1 m Student in Months 7-9)

Step 1.4 - Quantify how TES-derived ρ(z) and T(z) differ from in situ ρ(z) and T(z) measurements for Spirit and Opportunity EDL, including uncertainties (0.5 m Withers, 1 m Student in Months 10-12)

Step 1.5 - Collaborate with other groups using TES T(p) profiles to predict ρ(z) and T(z) for MSL EDL (0.5 m Withers, 1 m Student in Months 10-12)

Step 1.6 - Report results at site selection meeting (0.5 m Withers, 0.5 m Student in Months 13-15)

Deliverable 1.1 - Two ASCII files tabulating differences, with uncertainties, between TES-derived ρ(z) and T(z) and in situ ρ(z) and T(z) as function of z for Spirit and Opportunity EDL. Altitude range = 5 km to 40 km, vertical resolution = 100 m. Lower limit set by MER parachute deployment, upper limit set by TES, vertical resolution commensurate with MER observations and MSL EDL needs. To be delivered by email to MSL and MEP offices. Due at end of Month 12 (August 2008).

Objective 2: Derive representative $\rho(z)$ and T(z) profiles from TES T(p) profiles for candidate landing sites (Months 10 - 24)

Step 2.1 - Identify the current top ten candidate landing sites (minimal effort in Months 10-12)

Step 2.2 - Find all TES T(p) profiles consistent with the latitude, LST, and Ls of each of these ten sites (1 m Student in Months 10-12)

Step 2.3 - Reduce data quantity to a reasonable size by selecting 100 representative TES T(p) profiles for each of these ten sites (0.5 m Withers in Months 10-12)

Step 2.4 - Use results of Objective 1 to obtain $\rho(z)$ and T(z) profiles, with uncertainties and vertical resolutions, from each of these 100 x 10 TES T(p) profiles (0.5 m Withers, 1 m Student in Months 16-18)

Step 2.5 - Report results at site selection meeting (0.5 m Withers, 0.5 m Student in Months 22-24)

Deliverable 2.1 - Ten ASCII files tabulating 100 $\rho(z)$ and T(z), with uncertainties, between 0-30 km, one file for each of ten candidate landing sites. To be delivered by email to MSL and MEP offices. Due at end of Month 22 (June 2009).

Objective 3: Compare model ρ(z) predictions to MER EDL ρ(z) measurements (Months 13 - 24)

Step 3.1 - Attend site selection meeting and meet with scientists using models to predict ρ(z) (0.5 m Withers, 0.5 m Student in Months 13-15)

Step 3.2 - Acquire existing predictions of ρ(z) for Spirit and Opportunity EDL (0.5 m Withers, 0.5 m Student in Months 16-18)

Step 3.3 - Compare predictions and observations, record observations used in simulation (0.5 m Withers, 1 m Student in Months 19-21)

Step 3.4 - Collaborate with groups developing new versions of models and validating them against the Spirit and Opportunity EDL (0.5 m Withers, 1.5 m Student in Months 22-24)

Step 3.5 - Report results at site selection meeting (0.5 m Withers, 0.5 m Student in Months 22-24)

Deliverable 3.1 - For each available simulation, ASCII file tabulating differences between predicted and in situ ρ(z) as function of z. Altitude range = 5 km to 40 km, vertical resolution = 100 m. Lower limit set by MER parachute deployment, upper limit exceeds 30 km stated in RFP, vertical resolution commensurate with MER observations and MSL EDL needs. Also describe whether each simulation assimilated near-real-time orbital data or used longer-term climatic data as boundary conditions. To be delivered by email to MSL and MEP offices. Due at end of Month 22 (June 2009).

Objective 4: Archive Spirit and Opportunity entry profiles (Months 25 - 36)

Step 4.1 - Determine vertical profiles of ρ, p, and T for Spirit and Opportunity EDL (already accomplished)

Step 4.2 - Generate PDS documentation, such as AAREADME.TXT, VOLDESC.CAT, DATASET.CAT, INDEX files, DOCUMENT files, including Software Interface Specification file, and BROWSE images (1 m Withers, 1 m Student in Months 25-27)

Step 4.3 - Convert data products into PDS-compliant formats (1 m Withers, 1.5 m Student in Months 25-27)

Step 4.4 - Revise data products and documentation based on inspection by PDS personnel; deliver to PDS (0.5 m Withers, 1 m Student in Months 28-30)

Step 4.5 - Participate in PDS peer review of data products and documentation (0.5 m Withers, 0.5 m Student in Months 31-33)

Step 4.6 - Revise data products and documentation based on PDS peer review; deliver to PDS (1 m Withers, 2 m Student in Months 34-36)

Deliverable 4.1 - Peer-reviewed PDS volume containing Spirit and Opportunity ρ, p, and T profiles from EDL and documentation are available online at the PDS. Due at end of Month 36 (August 2010).

Deliverable 4.2 - CDs containing PDS volume mailed to MSL and MEP offices. Due at end of Month 36 (August 2010).

Reporting Deliverables	Due at end of Month #
R1 - Quarterly Progress Report for Months 1-3	3
R2 - Quarterly Progress Report for Months 4-6	6
R3 - Quarterly Progress Report for Months 7-9	9
R4 - Quarterly Progress Report for Months 10-12	12
R5 - Quarterly Progress Report for Months 13-15	15
R6 - Quarterly Progress Report for Months 16-18	18
R7 - Quarterly Progress Report for Months 19-21	21
R8 - Quarterly Progress Report for Months 22-24	24
R9 - Quarterly Progress Report for Months 25-27	27
R10 - Quarterly Progress Report for Months 28-30	30
R11 - Quarterly Progress Report for Months 31-33	33
R12 - Quarterly Progress Report for Months 34-36	36
R13 - Semi-annual telecon with MSL Project Scientists for Months 1-6	6
R14 - Semi-annual telecon with MSL Project Scientists for Months 7-12	12
R15 - Semi-annual telecon with MSL Project Scientists for Months 13-18	18
R16 - Semi-annual telecon with MSL Project Scientists for Months 19-24	24
R17 - Semi-annual telecon with MSL Project Scientists for Months 25-30	30
R18 - Semi-annual telecon with MSL Project Scientists for Months 31-36	36
R19 - Annual progress report for Months 1-12	12
R20 - Annual progress report for Months 13-24	24
R21 - Annual progress report for Months 25-36	36
R22 - Final report for Months 1-36	36
R23 - Send three copies of all technical papers produced as a result of this work to JPL	36

Budget Narrative

Effort of PI Paul Withers is 4 months FTE per year.
Effort of Boston University Graduate Student is 6 months FTE per year
Unfunded effort of Collaborator Mike Smith is ~1 week per year

Travel will be divided between Withers and Student to ensure that Student gains experience by attending site selection meetings and scientific conferences.

Domestic Travel
2 person-trips per year to 3-day site selection meetings.
2 person-trips in Year 1 to 5-day scientific conference (eg DPS, AGU).
2 person-trips in Year 2 to 5-day scientific conference (eg DPS, AGU).

Domestic site selection meetings:
Justification: Site selection meetings are the primary forum for discussion of MSL's atmospheric prediction needs and interactions with MSL Project personnel.

Domestic scientific conferences:
Justification: Train Student to present results at professional meetings, exchange ideas with colleagues, advertise results to colleagues who are not yet involved in the MSL Project and receive feedback from them.

Foreign Travel
2 person-trips in Year 3 to 5-day scientific conference (eg EGU).

Foreign scientific conferences:
Justification: A foreign conference with relevant special sessions or a foreign location for an American (e.g. DPS, Spring AGU) conference will occasionally be more appropriate than a domestic scientific conference.

Publication costs per year, based on JGR page charges = $500
Supplies per year (long-distance telephone, fax, delivery services) = $500
Software and network hookup costs per year = $500

No exceptions to the General Provisions or Additional General Provisions are requested at this time.