# Simplifying the martian carbon dioxide cycle: An empirical method for predicting surface pressure

Paul Withers[1], Silvia Tellmann[2]

1 - Boston University

2 – Rheinisches Institut fur Umweltforschung, Cologne, Germany

(withers@bu.edu)

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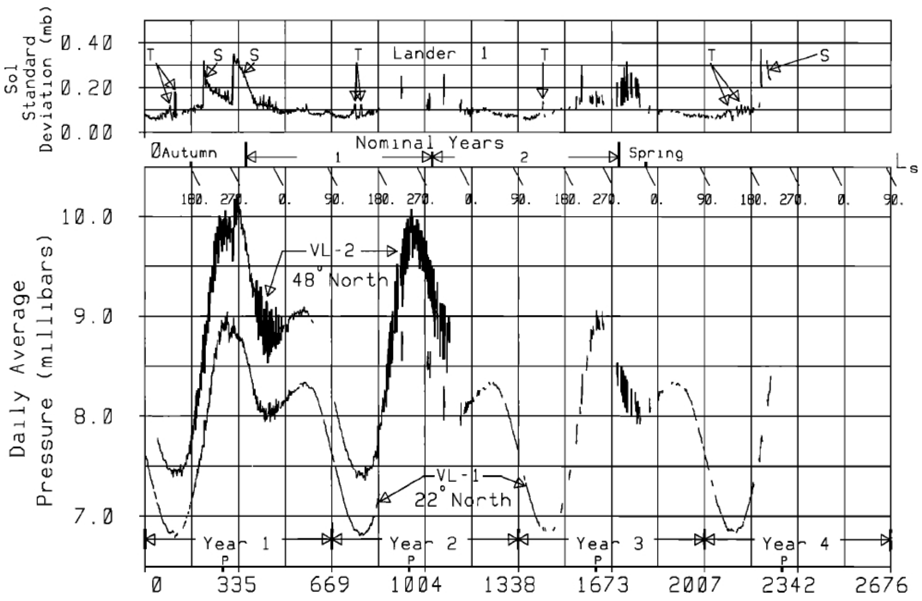


Atmospheric Pressure at the Surface of Mars (All years)

# Background

Viking Lander pressure data
Fig 1 of Tillman et al. (1993)

- Martian surface pressure exhibits significant spatial and temporal variations
- Accurate predictions of surface pressure have a range of applications, including
  - Polar energy balance studies
  - Geodetic studies of rotation state and gravity field
  - Derivation of absolute altitude scales for T(p) profiles
  - Landing site evaluations
- Objective is to find a simple empirical expression that can predict diurnal-mean surface pressure
  - Ease of application, transparency desired
  - Minimize use of complicated models
  - Validate against observations
- Optimize for MSL landing conditions (Ls=120 to 180, z<+1 km, 45S to 45N), but desire adequate predictions for all conditions

# Available Datasets

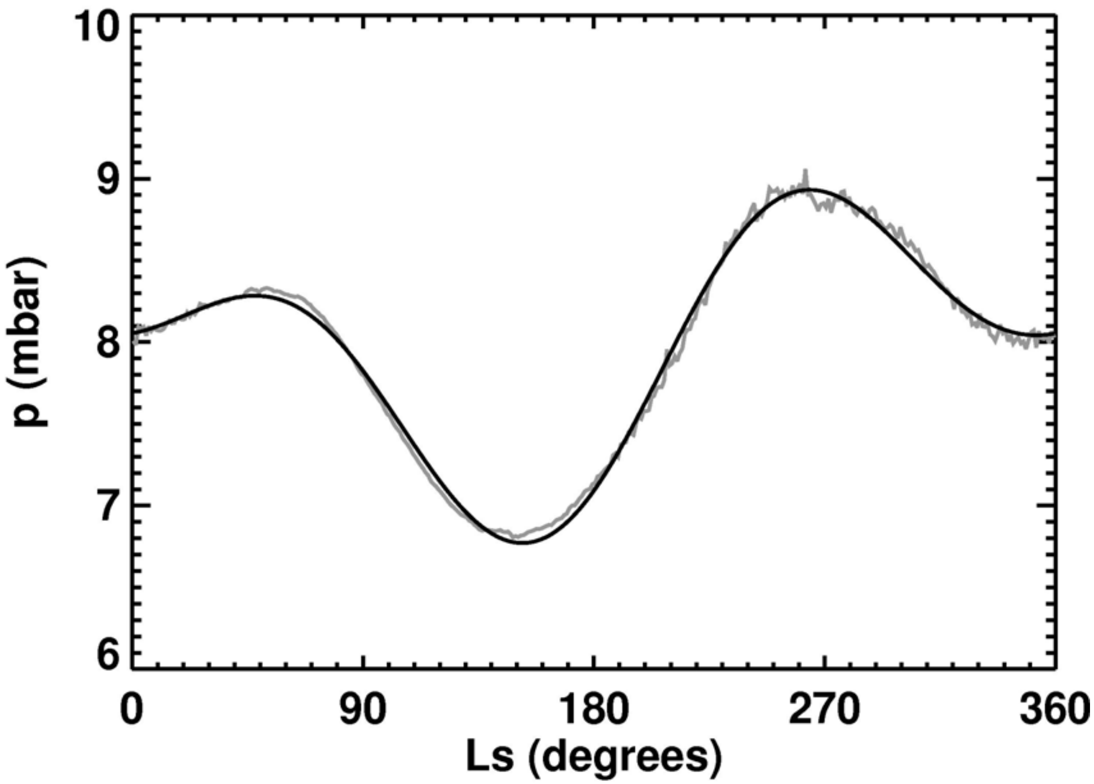
- <u>LANDERS</u>
- VL1
  - Multiple years, coarse digitization, 22N
- VL2
  - Almost one year, coarse digitization, 48N
- MPF
  - Ls=142-188, same elevation as VL1, systematic error of about 0.1 mbar, 19N
- PHX
  - Ls=76-151, 68N, large and precise dataset
  - Data from Ls=120 to 151 not yet incorporated into analysis

- <u>RADIO OCCULTATIONS</u>
- Mariner 9
  - Apparent inconsistencies of 10%
- VO1 and VO2
  - Barely 20 pressures reported
- MGS
  - 21243 profiles, including 297 at Ls=120-180, z<+1 km, latitude=45S to 45N
  - Extrapolate p(r) to MOLA surface and assign MOLA altitude
- MEX
  - 484 profiles, only 5 at Ls=120-180, z<+1 km, latitude=45S to 45N

Most useful datasets are: VL1 for seasonal cycle, MGS for validation and testing,

Goal is: Simple expression for DIURNAL MEAN Ps as function of season and altitude.

# Approach




Grey line is 360 diurnal mean surface pressure from VL1

Black line is wave-2 fit

| Parameter | VL1 |
|---|---|
| $p_0$ (mbar) | 7.9723740 |
| $s_1$ | -0.068622849 |
| $c_1$ | 0.060390972 |
| $s_2$ | 0.044663631 |
| $c_2$ | -0.050183946 |

Use expression below to predict surface pressure, Ps
zVL1 = -3.63 km
Constant and uniform H0 needed (found on next slide)

$$p_s = p_{0,VL1} \exp\left(-\left(z - z_{VL1}\right)/H_0\right) \times$$ Eqn 1

$$\left(1 + s_{1,VL1} \sin\left(1L_s\right) + c_{1,VL1} \cos\left(1L_s\right) + s_{2,VL1} \sin\left(2L_s\right) + c_{2,VL1} \cos\left(2L_s\right)\right)$$

Optimize with Delta metric, where Delta = (p-pred – p-meas) / p-meas

# Finding H0 from MGS

| $L_s$ range | N | $\bar{z}$ (km) | $H_0$ (km) | $\overline{\Delta}$ | S. D. of $\Delta$ |
|---|---|---|---|---|---|
| 340°–20° | 293 | -1.3 | 10.0 | -2.1E-02 | 3.2E-02 |
| | | | 10.5 | -9.9E-03 | 2.5E-02 |
| | | | 11.0 | 1.5E-04 | 2.3E-02 |
| | | | 11.5 | 9.5E-03 | 2.6E-02 |
| | | | 12.0 | 1.8E-02 | 3.2E-02 |
| 20°–65° | 824 | -2.9 | 10.0 | -4.1E-03 | 1.5E-02 |
| | | | 10.5 | -8.5E-04 | 1.0E-02 |
| | | | 11.0 | 2.2E-03 | 1.0E-02 |
| | | | 11.5 | 5.1E-03 | 1.4E-02 |
| | | | 12.0 | 7.7E-03 | 1.9E-02 |
| 65°–120° | 740 | -2.2 | 10.0 | -1.4E-02 | 1.9E-02 |
| | | | 10.5 | -7.2E-03 | 1.5E-02 |
| | | | 11.0 | -1.1E-03 | 1.4E-02 |
| | | | 11.5 | 4.6E-03 | 1.6E-02 |
| | | | 12.0 | 9.9E-03 | 1.9E-02 |
| 120°–175° | 297 | -1.7 | 10.0 | -3.4E-02 | 2.6E-02 |
| | | | 10.5 | -2.5E-02 | 2.1E-02 |
| | | | 11.0 | -1.7E-02 | 1.8E-02 |
| | | | 11.5 | -9.7E-03 | 1.7E-02 |
| | | | 12.0 | -2.9E-03 | 1.8E-02 |

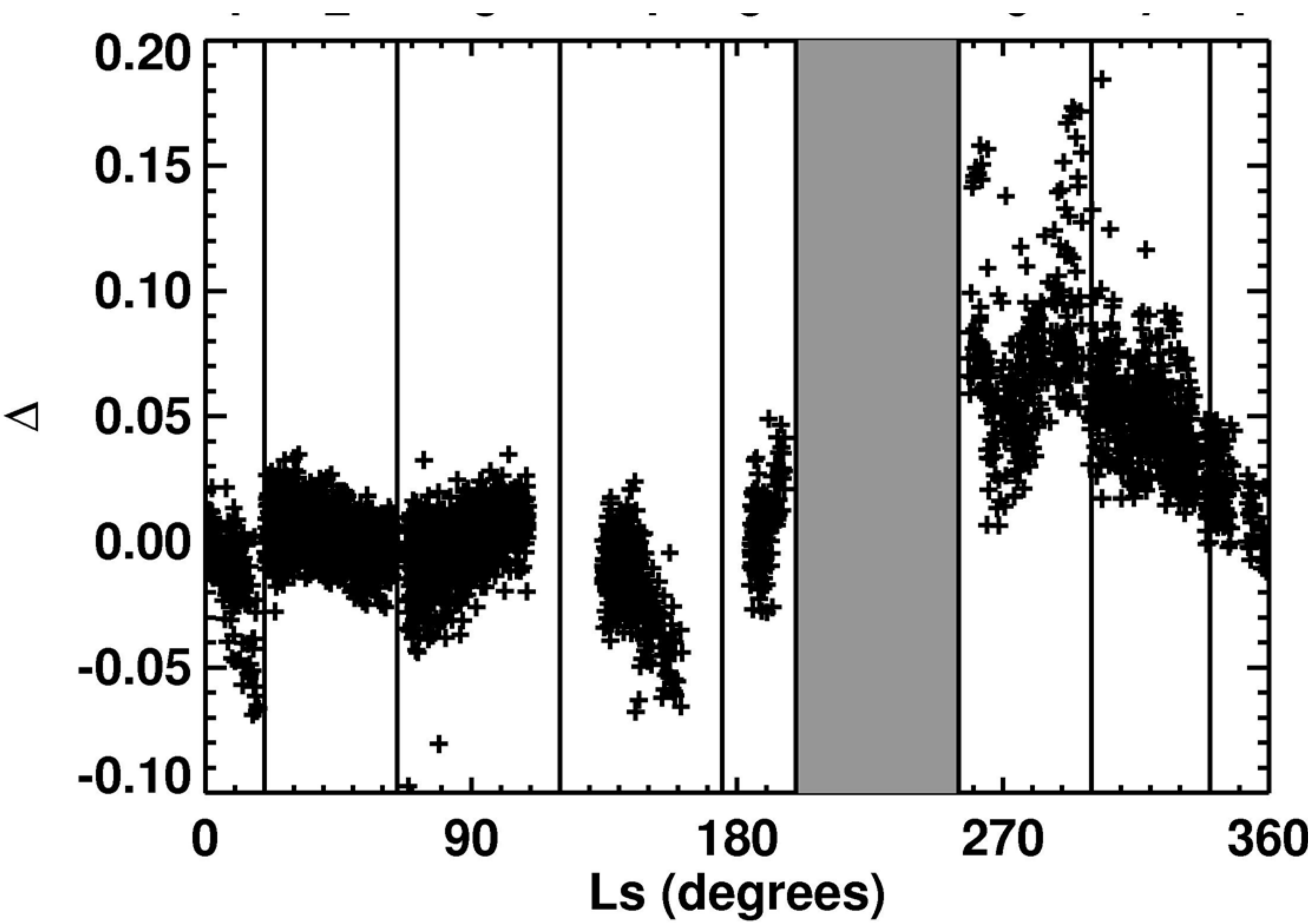
- Quickly find that H0<10 km and H0>12 km have problems at low and high altitudes
- MGS measurements at z<+1 km and 45S to 45N divide neatly into seven Ls blocks

| $L_s$ range | N | $\bar{z}$ (km) | $H_0$ (km) | $\overline{\Delta}$ | S. D. of $\Delta$ |
|---|---|---|---|---|---|
| 175°–200° | 127 | -2.8 | 10.0 | -2.2E-04 | 1.9E-02 |
| | | | 10.5 | 3.7E-03 | 1.6E-02 |
| | | | 11.0 | 7.3E-03 | 1.6E-02 |
| | | | 11.5 | 1.1E-02 | 1.8E-02 |
| | | | 12.0 | 1.4E-02 | 2.1E-02 |
| 255°–300° | 306 | -1.0 | 10.0 | 4.8E-02 | 4.4E-02 |
| | | | 10.5 | 6.1E-02 | 3.7E-02 |
| | | | 11.0 | 7.3E-02 | 3.2E-02 |
| | | | 11.5 | 8.3E-02 | 2.9E-02 |
| | | | 12.0 | 9.4E-02 | 2.7E-02 |
| 300°–340° | 479 | -1.3 | 10.0 | 2.6E-02 | 2.9E-02 |
| | | | 10.5 | 3.8E-02 | 2.3E-02 |
| | | | 11.0 | 4.8E-02 | 2.0E-02 |
| | | | 11.5 | 5.8E-02 | 2.0E-02 |
| | | | 12.0 | 6.7E-02 | 2.3E-02 |

Optimal scale height is:

H0 = 11 km
Equivalent to T=215 K, which is reasonable

# Delta vs Ls for MGS



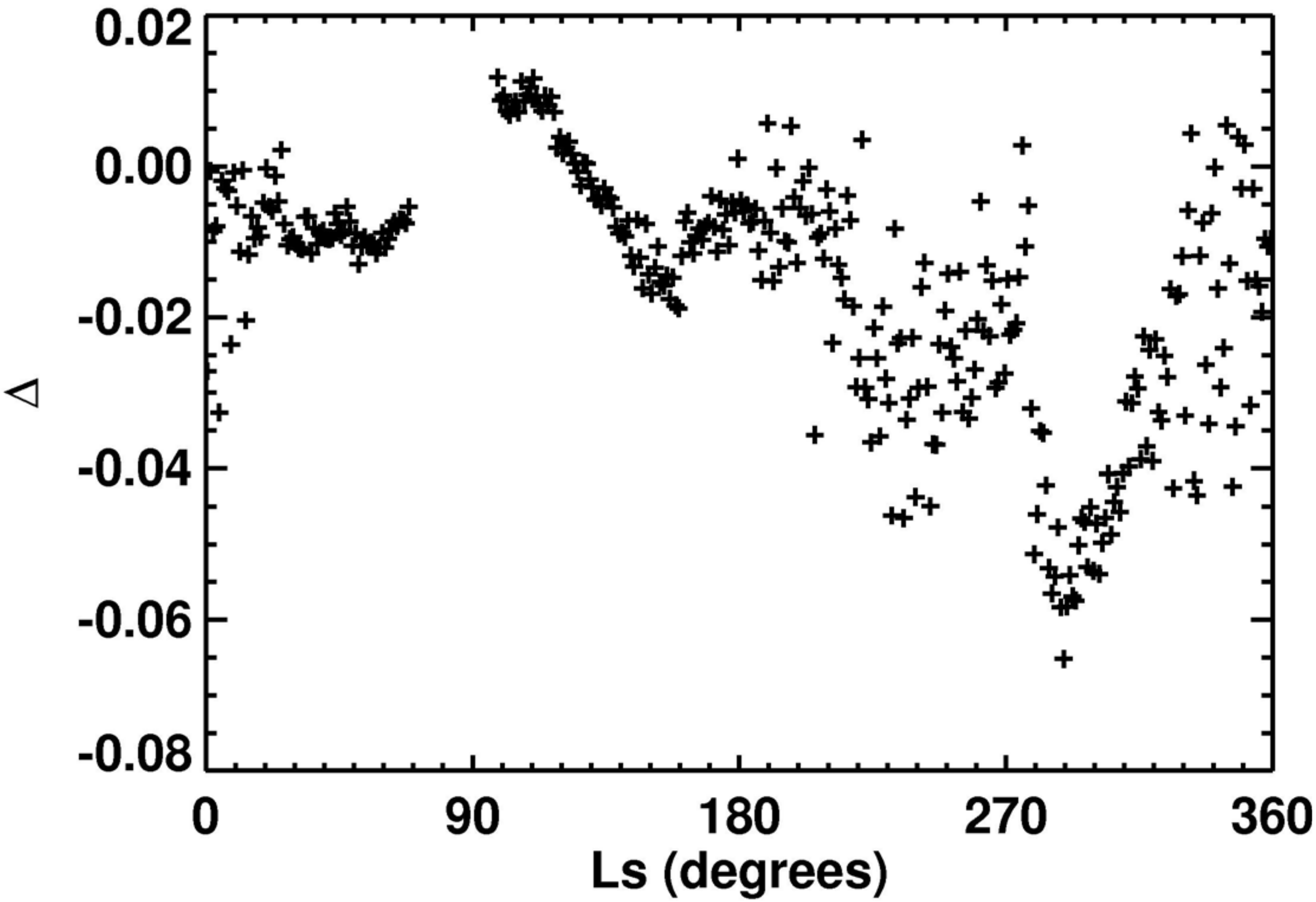

Poor predictions at Ls=255-340

OK at other seasons

Possible trend with Ls at Ls=120-175?

Only data from z<+1 km and 45S to 45N shown here

# Delta vs Ls for VL2




Poor predictions at Ls=240-360

OK at other seasons

Trend with Ls at Ls=110-160, similar to MGS?

Going to wave-4 in f(Ls) fixes this trend in VL1 and VL2, but has no effect on trend in MGS

So retain wave-2 for f(Ls)

# Accuracy of Predictions

| Mission | $\overline{\Delta}$ (all $L_s$) | S. D. of $\Delta$ (all $L_s$) | $\overline{\Delta}$ ($L_s = 120°$–$180°$) | S. D. of $\Delta$ ($L_s = 120°$–$180°$) |
|---|---|---|---|---|
| VL1 | 2.5E-3% | 0.6% | -0.4% | 0.6% |
| VL2 | 6.7E-3% | 1.1% | -0.4% | 0.6% |
| MPF | 2.2% | 0.2% | 2.2% | 0.2% |
| PHX | -0.2% | 3.0% | — | — |
| MGS | 1.4% | 3.2% | -1.7% | 1.8% |
| MEX | 0.2% | 3.3% | -7.1% | 7.0% |

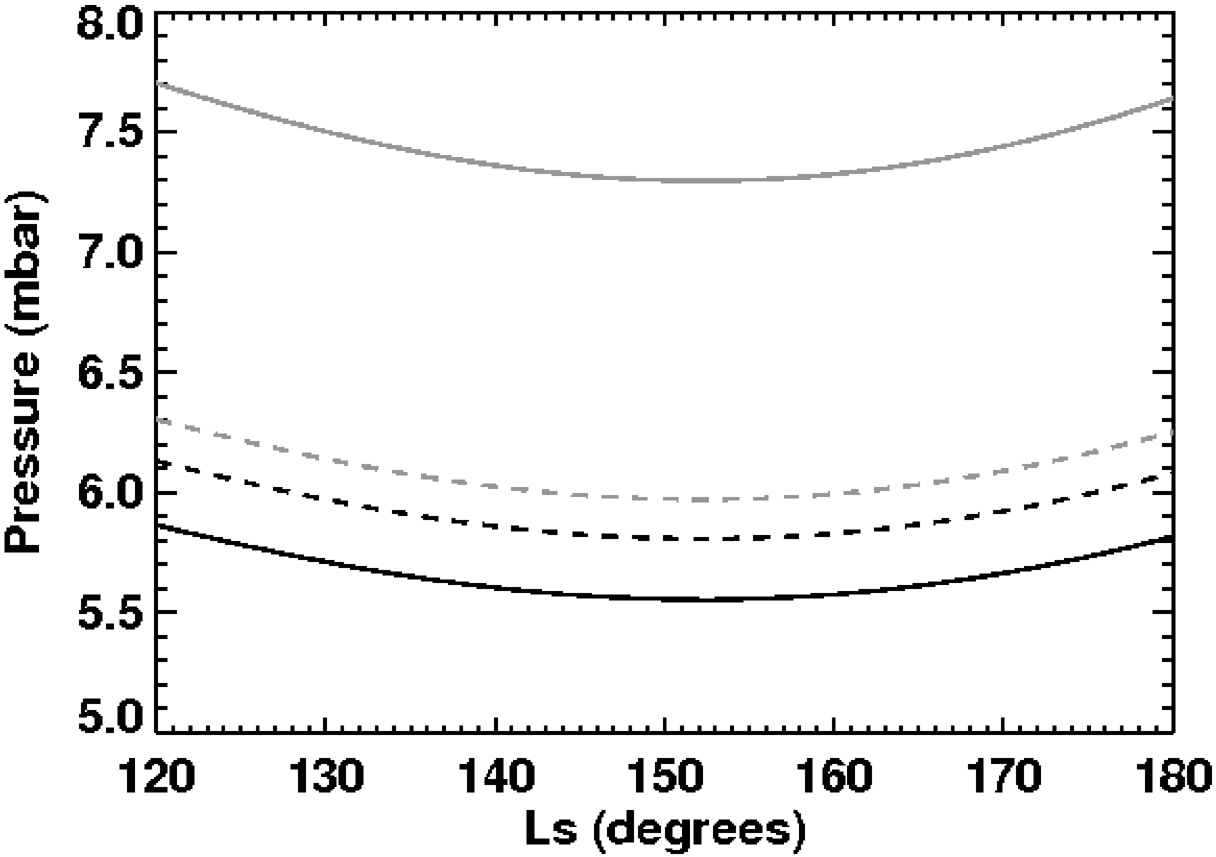
Expect 3% accuracy for MSL landing with 1-sigma confidence level

Overbar = Mean
S. D. = Standard deviation
Only data from z<+1 km and 45S to 45N used for orbital datasets

# Evaluation

- Data from VL1 and MGS were used to obtain predictive expression, so good predictions for these data should not be over-interpreted
- However, MGS data do span a very wide range of altitudes, latitudes, and longitudes
- VL2 results are encouraging
- MPF surface pressures are systematically too small by ~0.1 mbar, as noted by previous workers (Haberle et al., 1999) due to problems in pre-flight testing. Standard deviation of Delta is reassuringly small.
- PHX results are encouraging, especially coming from 68N, which is far north of the VL1 site at 22N
- MEX results at Ls=120 to 180 are influenced by “small number statistics” (5 profiles). Also, preliminary versions of MEX profiles were used here. Results improve when final versions are used.

# Predictions for MSL




Eberswalde (-1.450 km)
Solid black line
23.86S, 326.73E

Gale (-4.451 km)
Solid grey line
4.49S, 137.42E

Holden (-1.940 km)
Dashed black line
26.37S, 325.10E

Mawrth (-2.246 km)
Dashed grey line
24.01N, 341.03E

# Potential Applications

- First-order surface pressure estimates for landing site selection
- Reality-check on predictions from more complex, physics-based models
- Total atmospheric mass from Eqn 1 is about 10 $p_0R^2$ f(Ls) / g. Annual mean value is 2.4E16 kg and difference between maximum and minimum values is 6.6E15 kg, consistent with previous results.
- Correct orbital gamma ray and neutron spectrometer for atmospheric absorption effects
- Absolute altitude scales for T(p) profiles measured from orbit, such as MGS TES or Mariner 9 IRIS profiles
- Theoretical simulations of dust lifting and aeolian modification of surface features, the thermodynamic stability of near-surface liquids, and the surface radiation environment

# Conclusions

- A simple expression with 7 free parameters provides surprisingly accurate predictions for surface pressure
- Expected accuracy of prediction for MSL landing is 3% (1-sigma confidence level)
- Predictions are least accurate at Ls=240 to 360 when interannual variability (large dust storms) is greatest
- There are many potential applications for accurate surface pressure predictions